LAr R&D Program at BNL

Outline

1. Overview of LAr R&D program at BNL
2. Introductions
3. Experimental Setup
4. 2L and 20L results
5. LAr Field Calibration System (LArFCS)
6. Summary

Yichen Li

Oct 4th, 2016

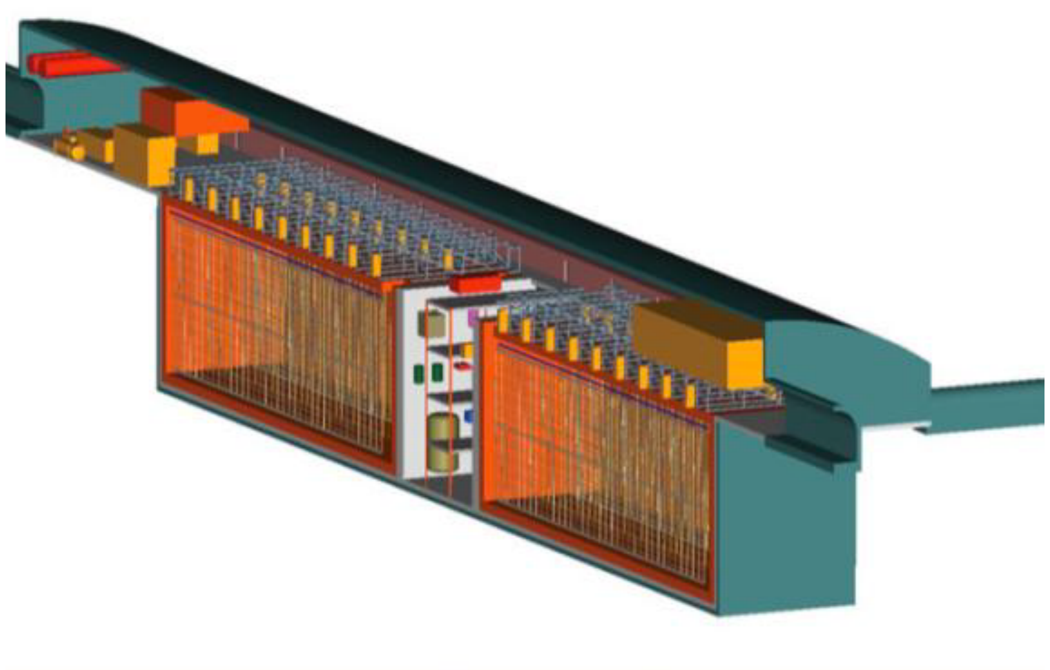
BROOKHAVEN NATIONAL LABORATORY

Overview: Large LAr TPC

Short-Baseline Neutrino (SBN) program and Deep Underground Neutrino Experiment (DUNE) with Liquid Argon Time Projection Chambers will address

- CP violation in the lepton sector
- Neutrino mass hierarchy
- Precision measurement of neutrinos
- Search for sterile neutrino(s)
- Proton decay
- Supernova neutrino detection

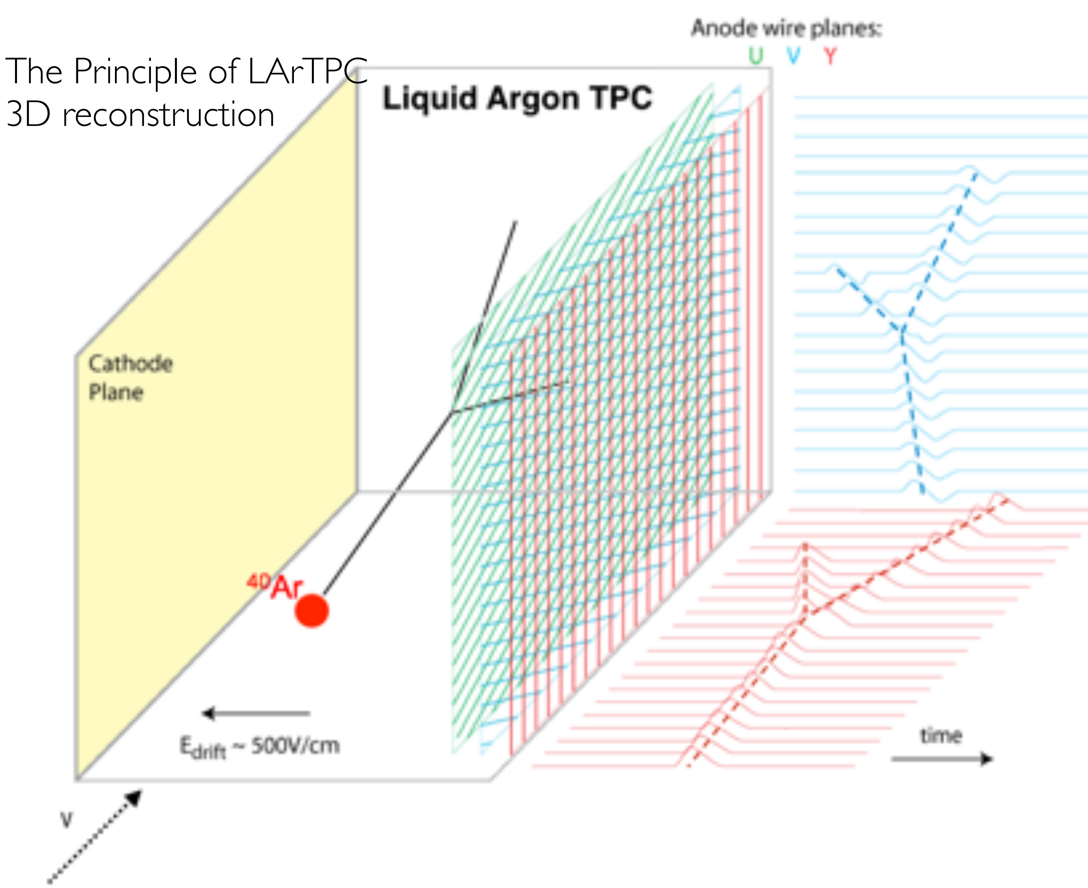
Characterizing the properties of LAr and understand the field response function of the LArTPC are very important for the design of the these detectors considering their high cost and long construction period



DUNE Single-Phase LAr TPC (40 kt)

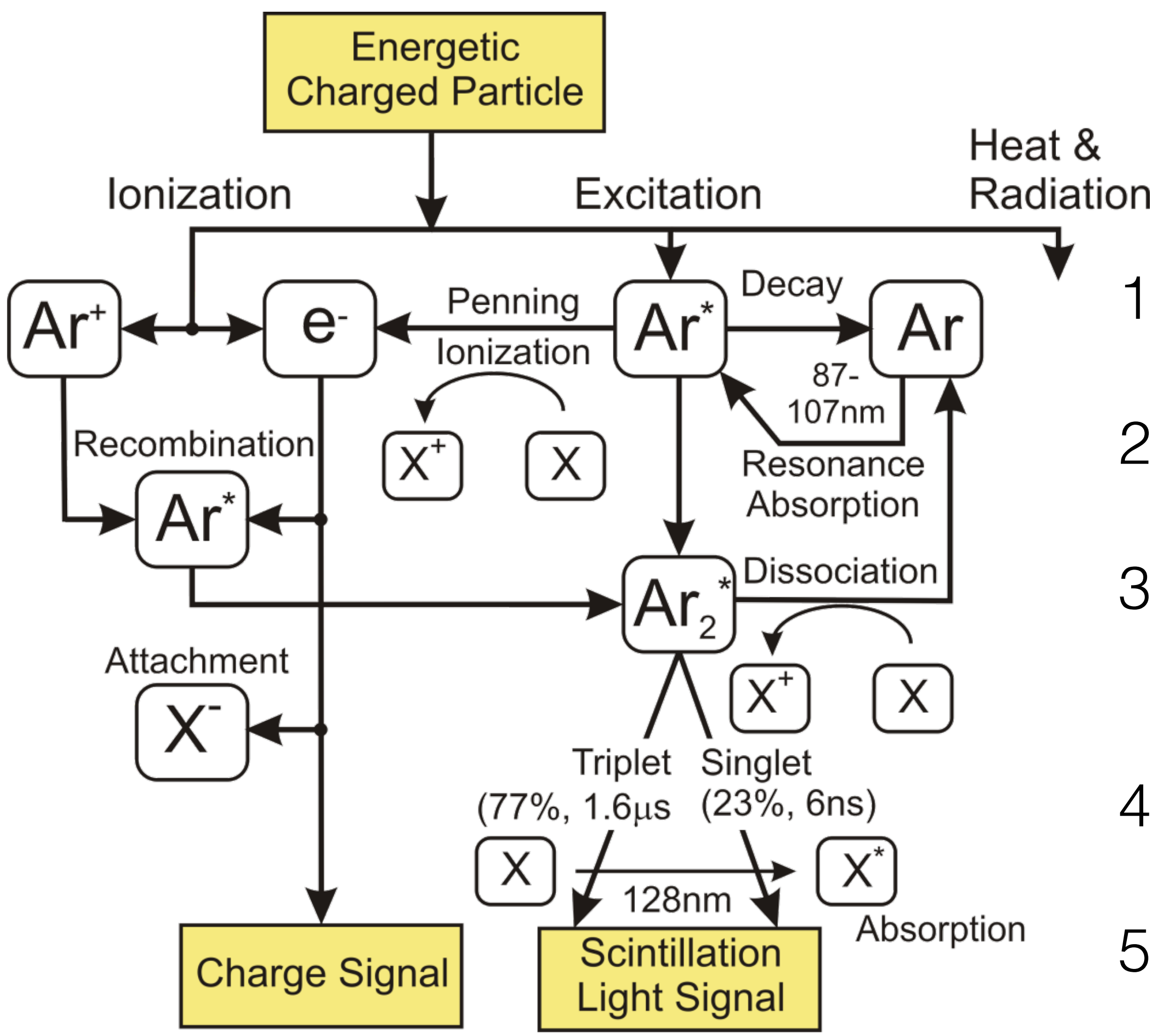
Drift length = 3.7 m

The Principle of LArTPC 3D reconstruction



Overview: BNL LAr R&D Program

- A good knowledge of properties of LAr and field response of LArTPC can help to design LArTPCs with better performance
- BNL has been carrying out a R&D program on study of LAr properties
- We are also planning to pursue the study of the fundamental property of LArTPC signal



Physics Goals

1. Measure electron transport properties
2. Develop and verify purification kinetics models
3. Study impurity adsorption/desorption kinetics, partition kinetics, and transport
4. Measure electron attachment
5. Measure the field response of LArTPC

Signal Processing in LArTPC

- Field response and electronics response are essential for LArTPC detector signal processing
- Electronics response is calibrated with dedicated pulser data
- We propose a direct calibration of field response function using LAr Field Calibration System (LArFCS)

Number of Ionized electrons

↓ *Field Response*

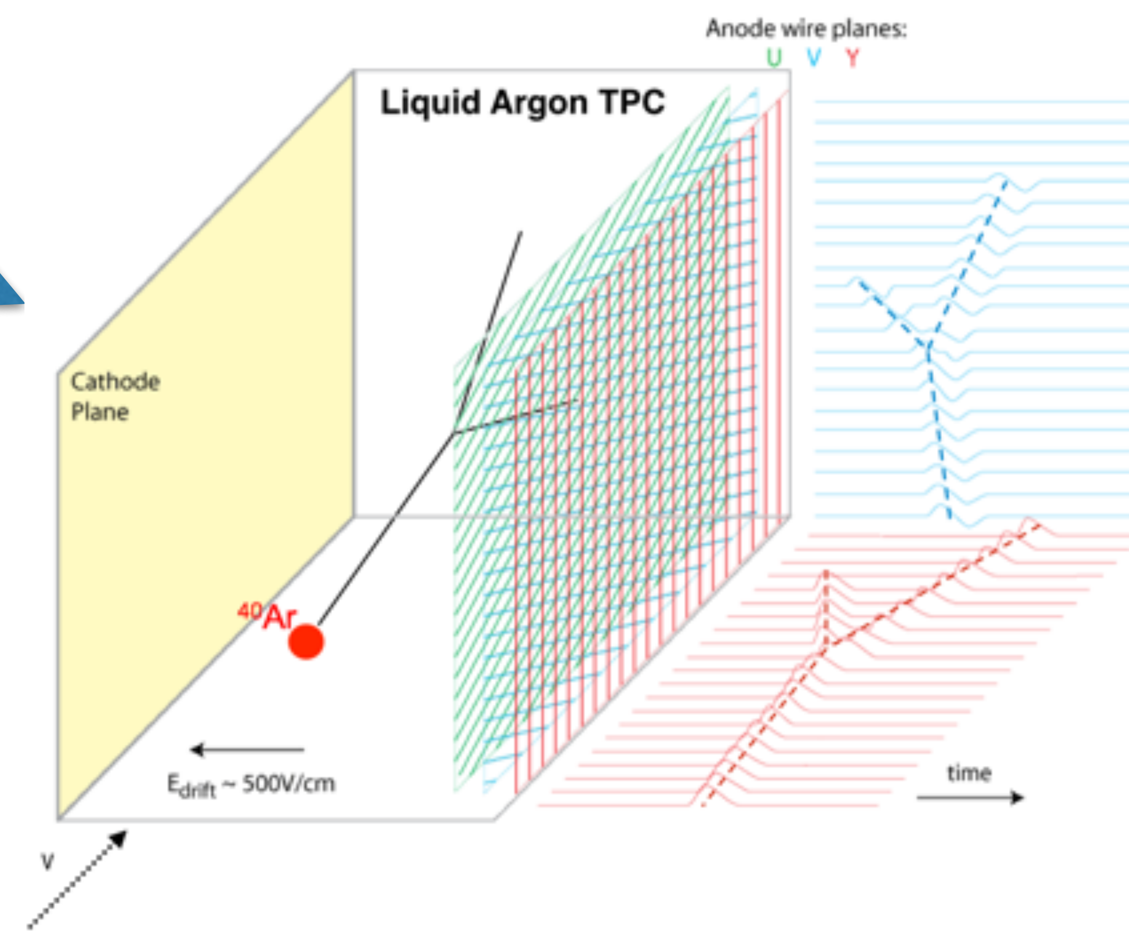
Signal on Wire Plane

↓ *Electronics Response* ✔

Signal to be digitized by ADC

↓ *Deconvolution*

Number of Ionized electrons

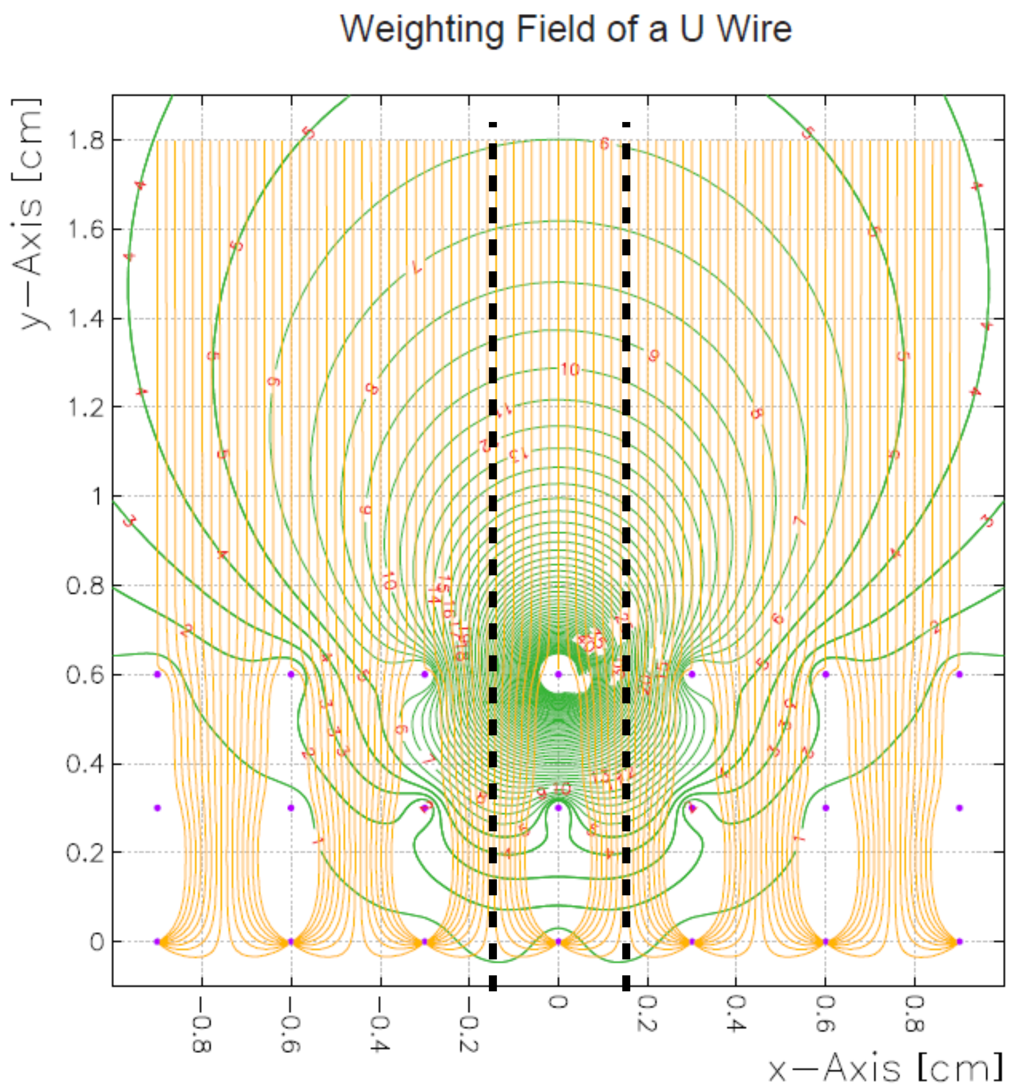


Physics behind Field Response Function

- The induction current is described by Shockley-Ramo theorem:

$$i = -qE_w v$$

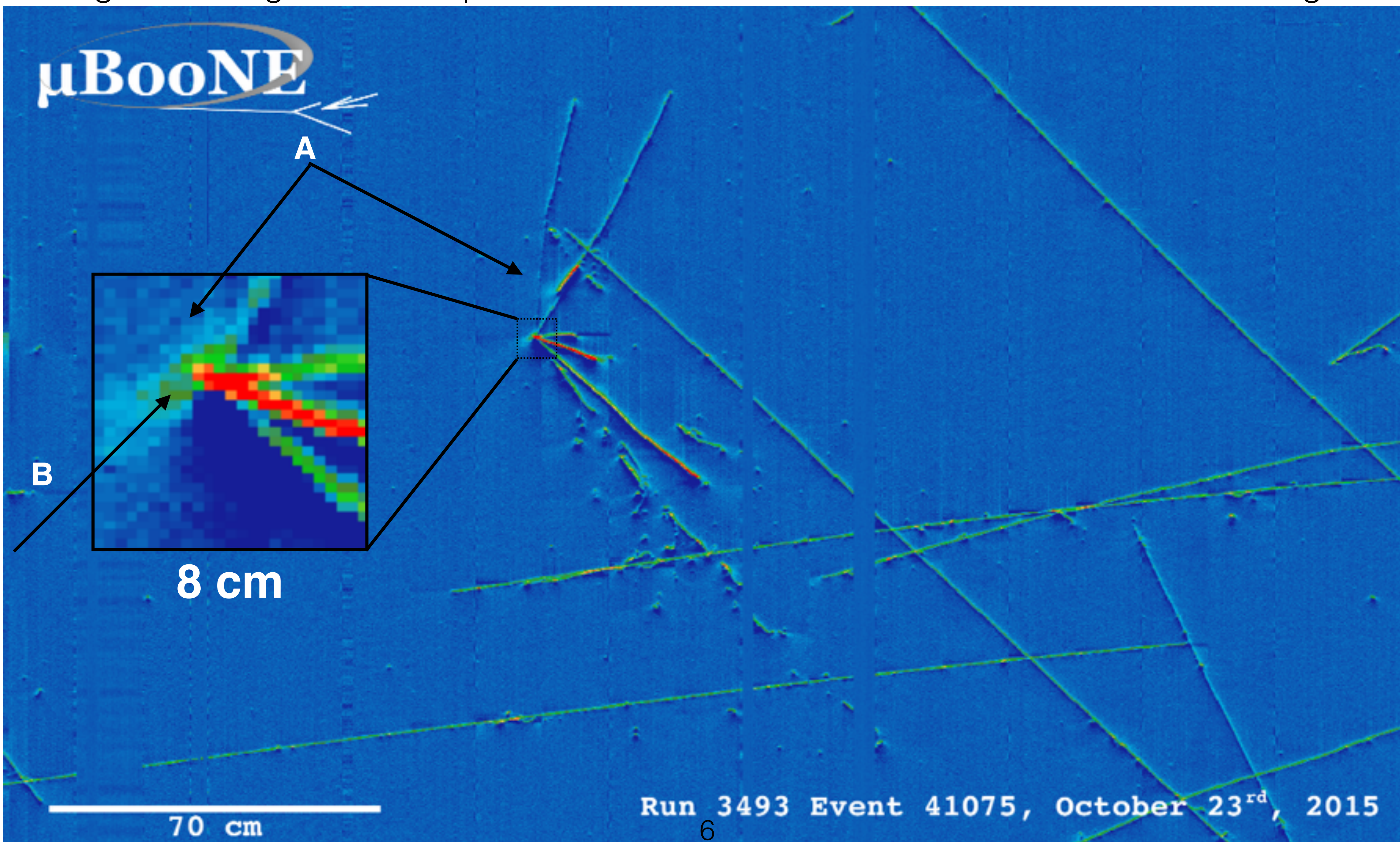
q-charge; E_w-weighting field; v-velocity



- $\boldsymbol{E_w}$ is the electric field for electrode with induction current at unit potential; and all other electrode at ground
- $\boldsymbol{E_w}$ extends beyond the boundary of wires (±half pitch), i.e., electrons pass through the adjacent wires can also produce induction current on the wire of interest
- ***v*** depends on electric field + location…..
- Induction current strongly depends on the local charge distribution

Events from MicroBooNE

- Variations on TPC signal shape are typically signifiant at the neutrino interaction vertex. (tracks are dense within several neighboring wires on induction plane)
- Reconstructing tracks close vertex correctly is critical for e/γ separation.
- Using an averaged field response function will lead to artificial effects on the image

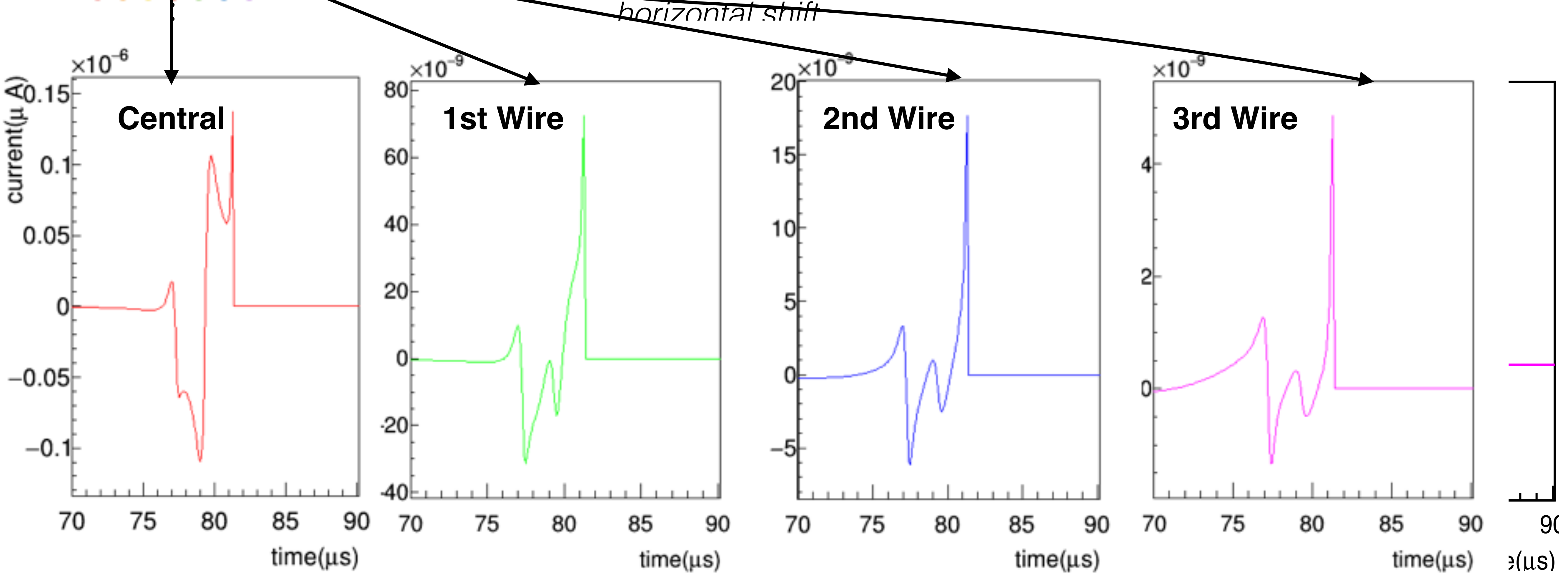


Prediction of Field Response Function

- Current prediction of field response function is based on Garfield-2D

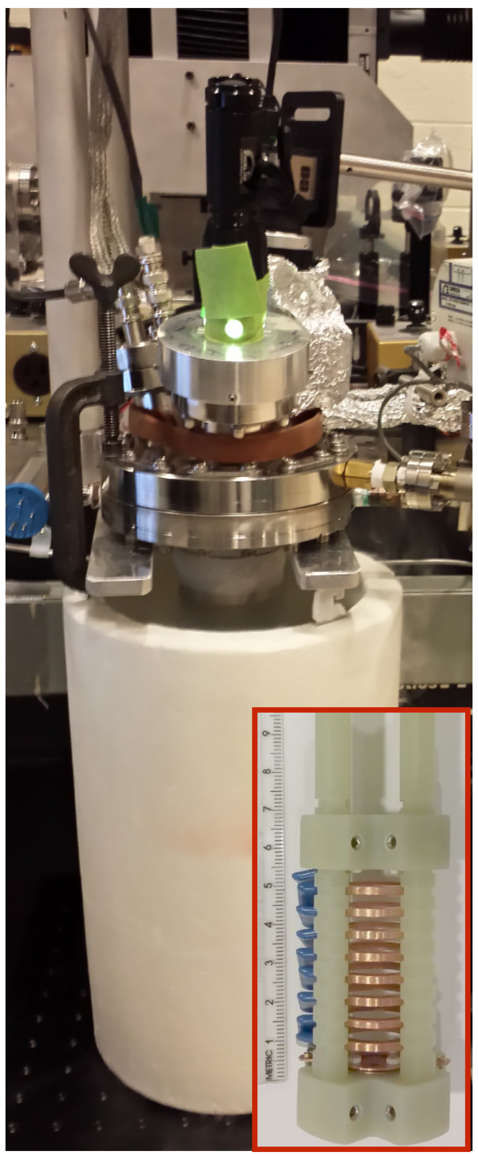
V Plane

- 2D results don't agree with data (e.g. time offset). 3D is most likely needed
- Due to various numerical difficulties, there is no realistic field response function in 3D available. Brett is currently working it
- We proposed a direct measurement to the field response



Experimental Setup

- 2L test stand is cooled by LN_2+Dry ice bath and LAr is formed by liquefying purified commercial GAr
- 20L test stand is an upgraded and improved apparatus with LAr circulation and GAr purification
- The LArFCS for demonstration of primary gas purification for LArTPC and field response calibration is currently under construction



2 L Test Stand

20 L Test Stand

LArFCS (800L)

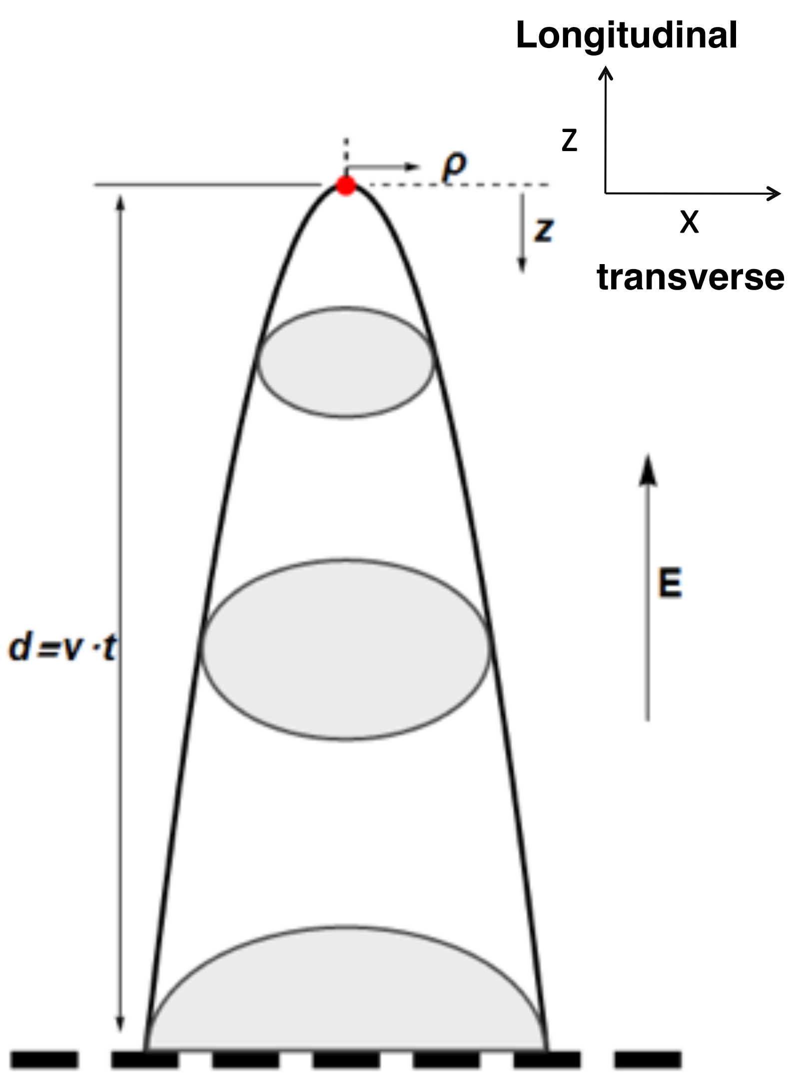
2L Test Stand: Diffusion of Electrons Drifting in LAr

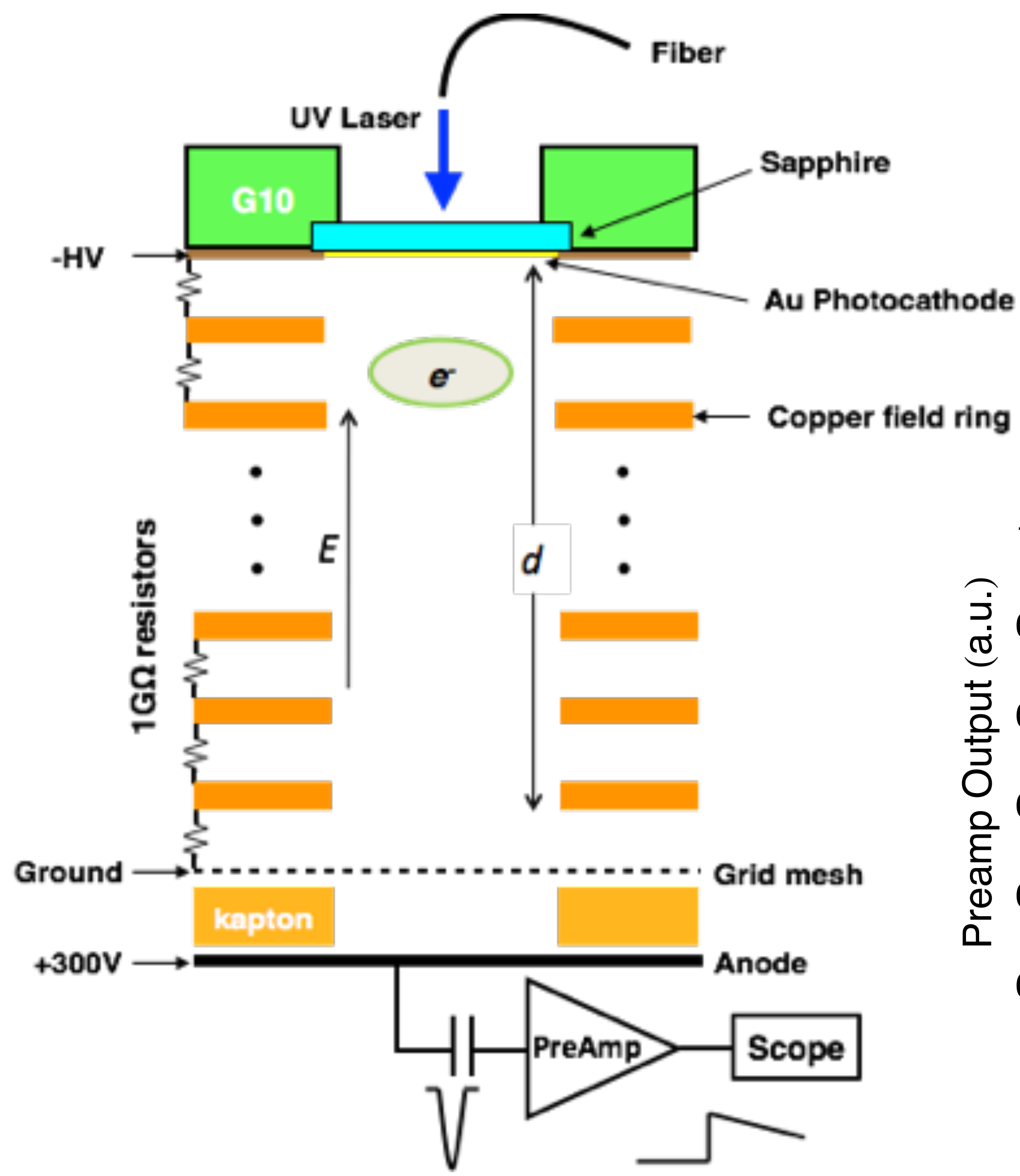
- Knowing electron diffusion after drift distance is crucial for understanding track resolution.

- Diffusion of electrons in strong electric fields is not isotropic.

- Drift velocity is measured by a time-of-flight method.

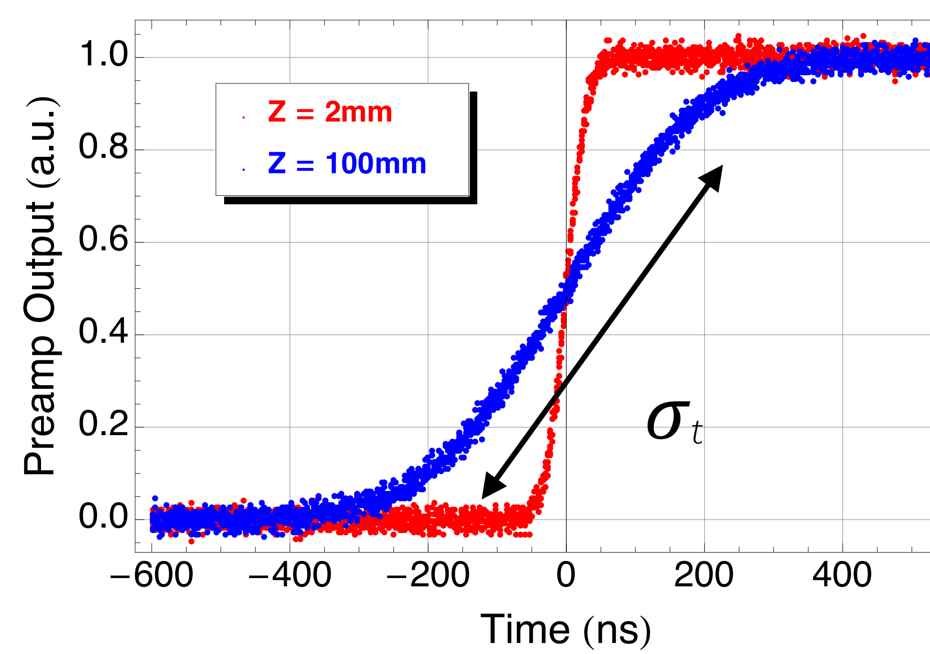
- Diffusion is measured by the signal rise time and interpreted by the electron energy





$$k_B T = \varepsilon_e = \frac{eD}{\mu}$$

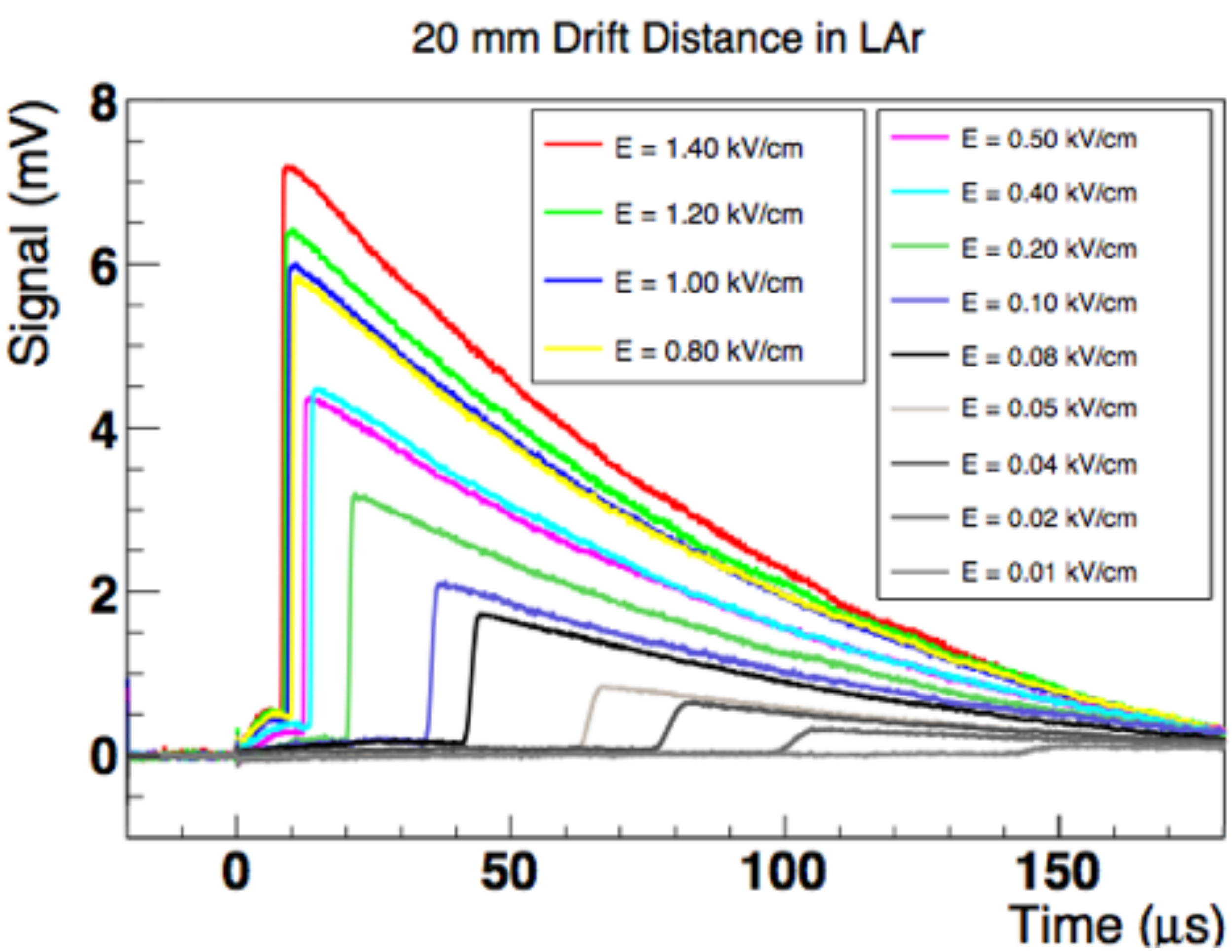
Simulated charge signal with drift offset removed

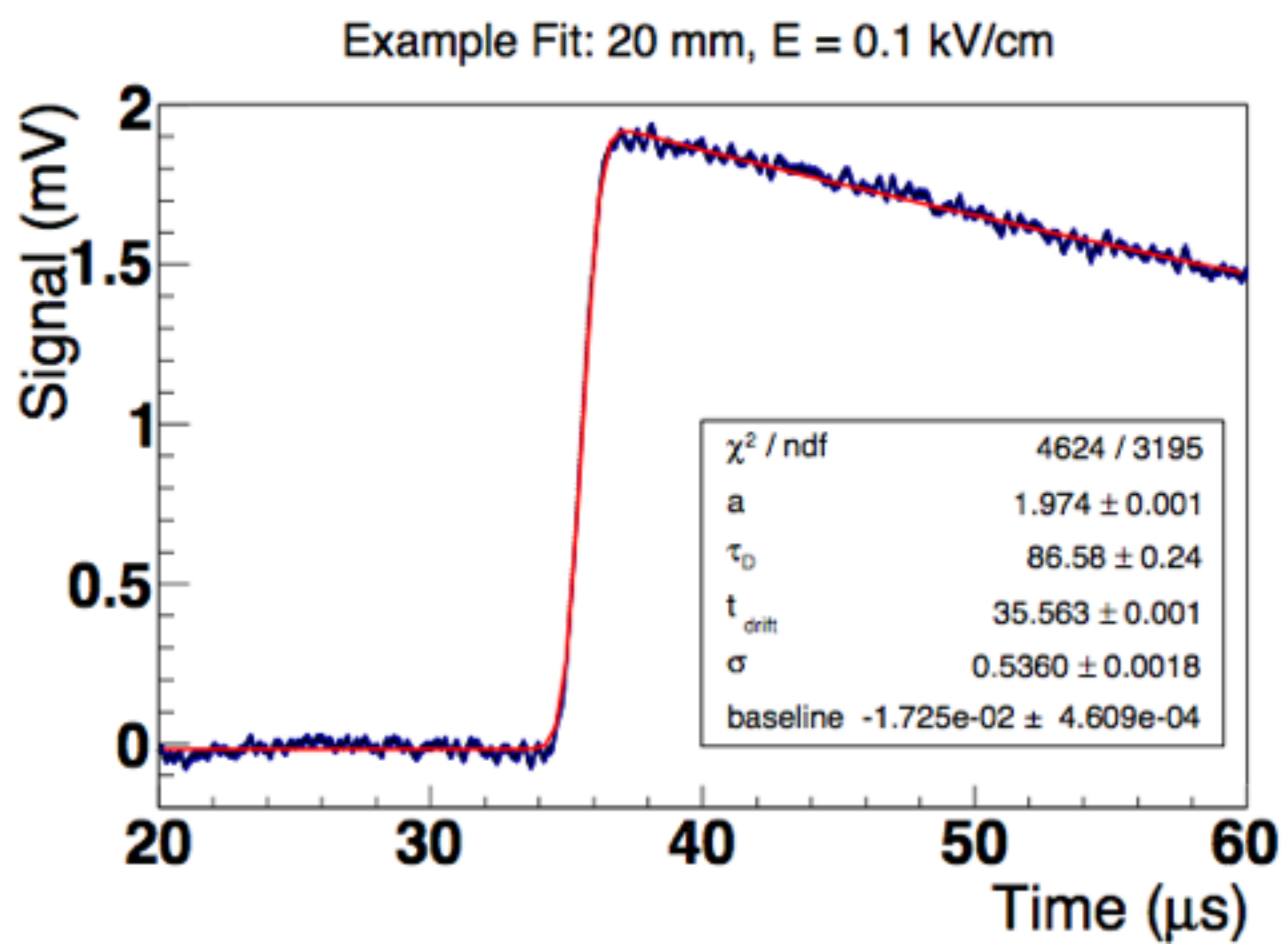


2L Test Stand: Raw Signal

- The anode charge signal is recorded with a digital oscilloscope for a set of high voltages and drift distances. It can be seen clearly on the plot that drift (rising edge position) and diffusion (slope of rising edge).

- The raw signal is fitted by a convolution of a Gaussian function containing the information of the electron swarm and a step response function with damping representing the response of the pre-amplifier.

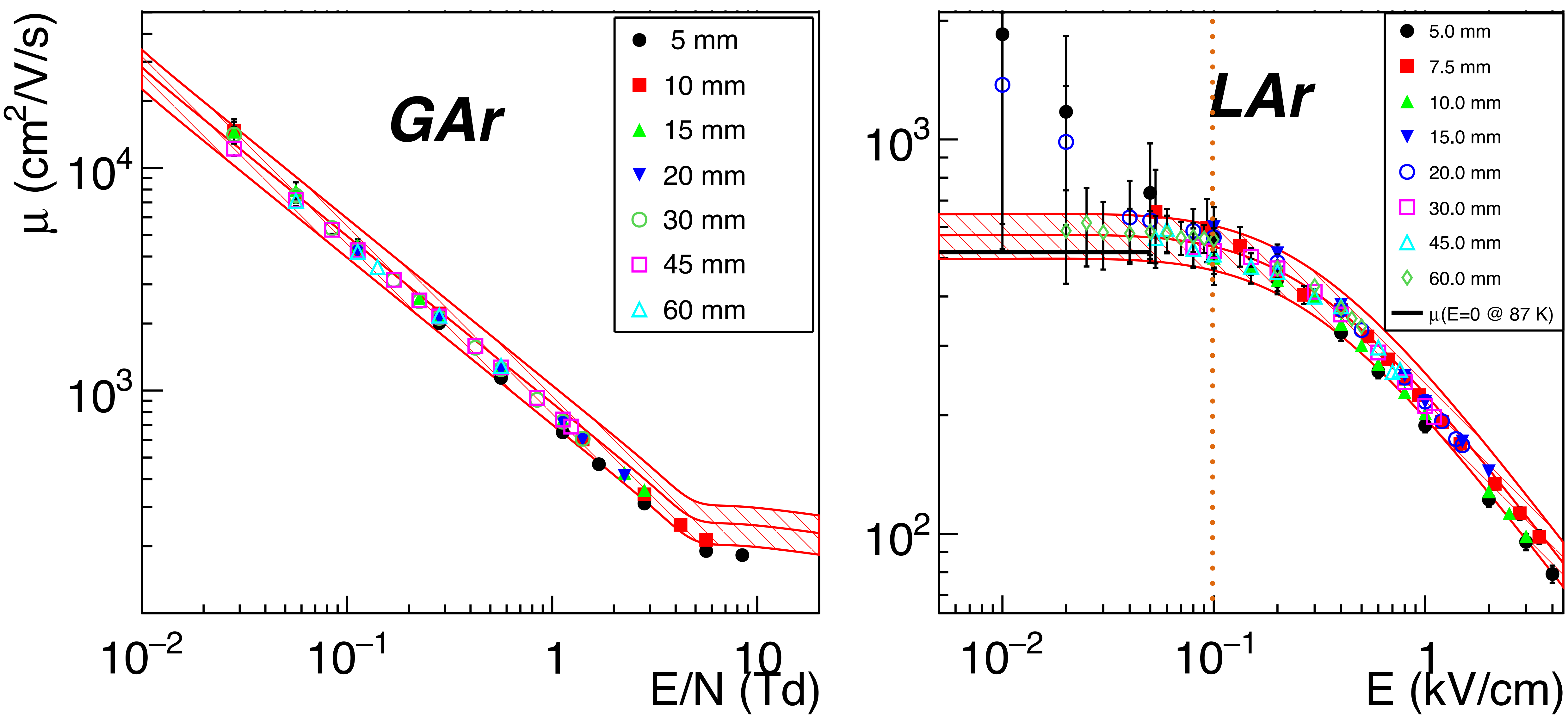




2L Test Stand: Electron Drift Velocity in LAr and GAr

- Our results agree with the global fit of previous measurements.
- Mobility at low fields is dominated by the field leakage effect for LAr, so we only report the diffusion > 0.1 kV/cm

$$v = \frac{d}{t} = \mu \cdot E$$

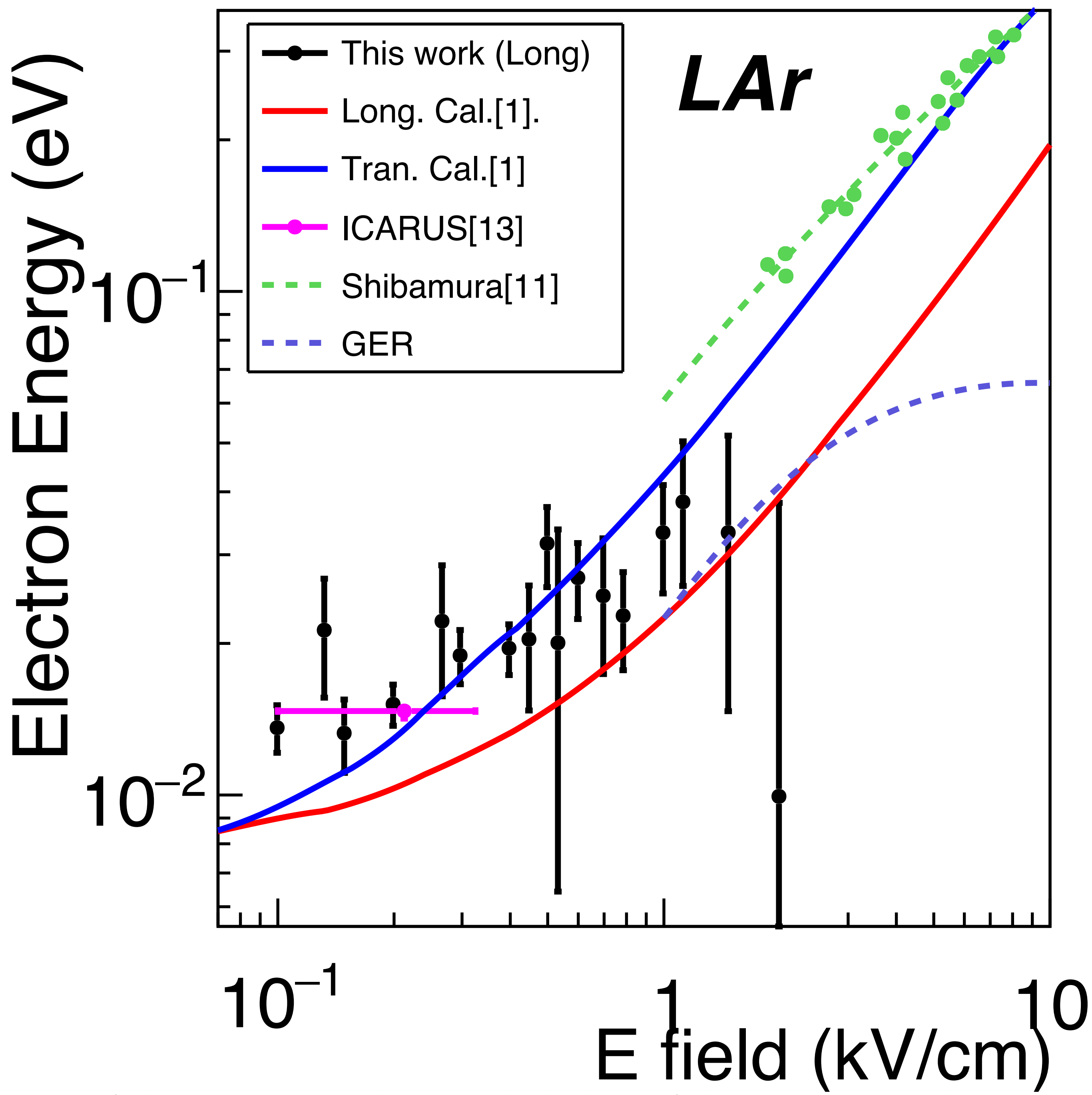


2L Test Stand: Electron Energy

- Our results agrees with previous results from ICARUS
- Our results are systematically higher than the calculation of Atrazhev et al.
- Details can be found in our paper on arXiv: 1508.07059 (submitted to NIM A)

- We are limited by the systematic uncertainties —> 20 L Test Stand

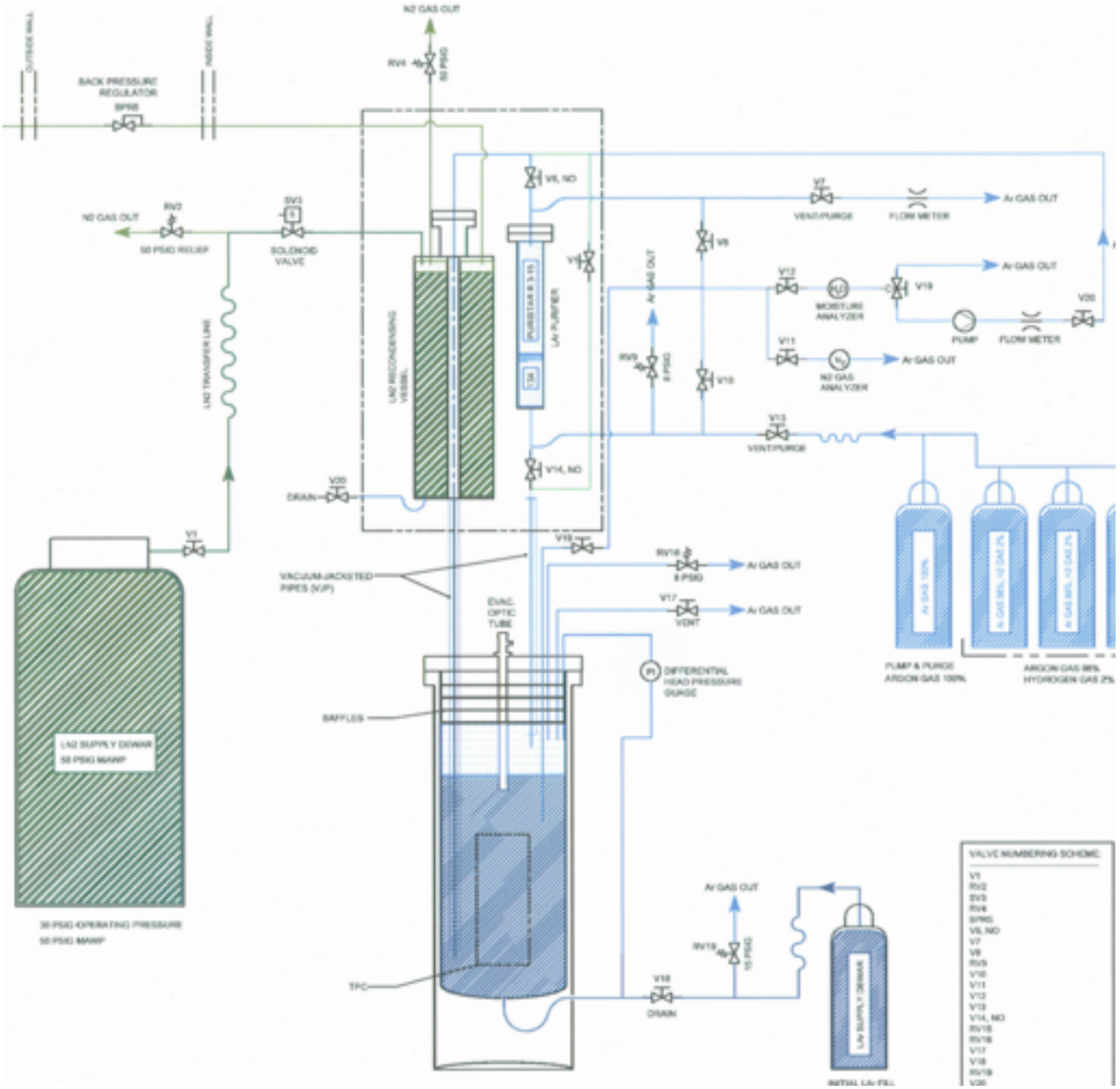
$$D = \frac{\mu k_B T}{e} = \frac{v}{Ee} k_B T$$



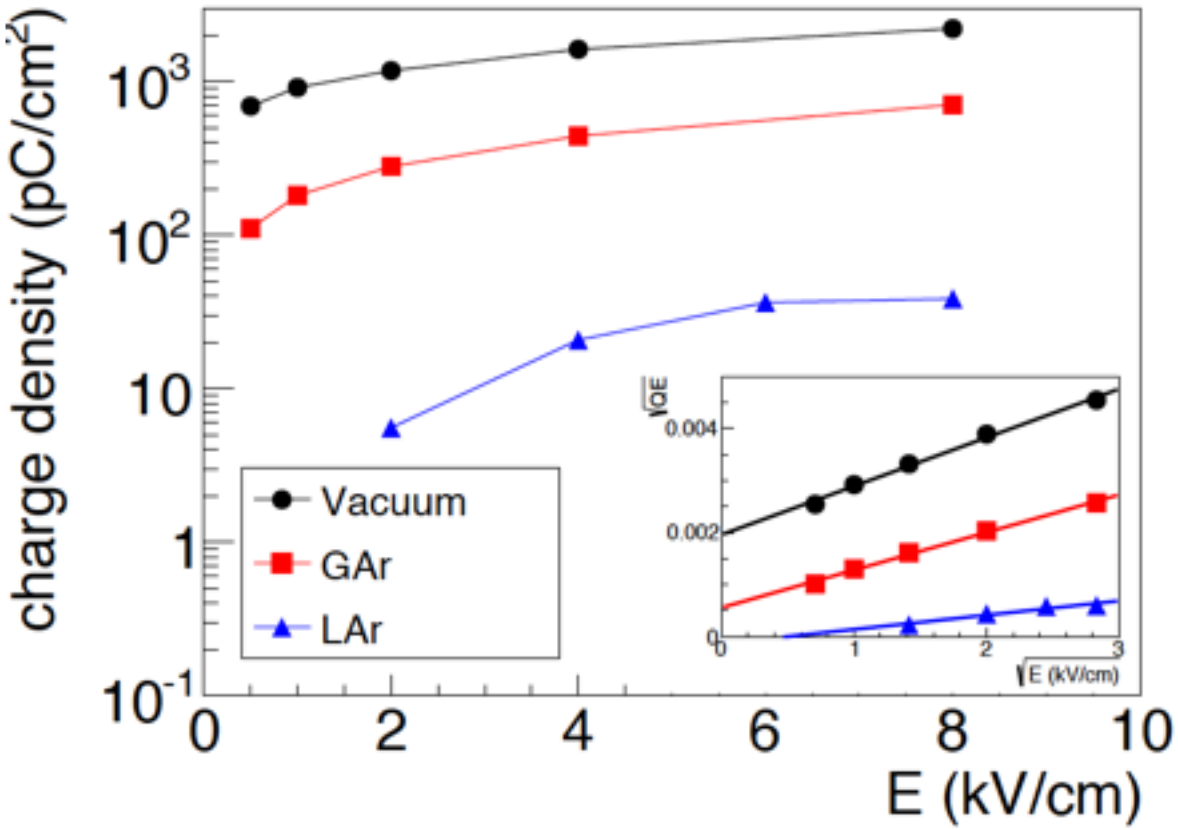
Ref: Atrazhev, V.M. and I.V. Timoshkin, Transport of electrons in atomic liquids in high electric fields, IEEE Trans. Dielectrics and Electrical Insulation

20L Test Stand

- The 20L test stand is constructed for improved measurement
  - Au photocathode illuminated by pulsed UV laser is used as electron source
  - The pre-amplifier is integrated with the anode immersed in LAr
  - Finer grid mesh
- Ultra high purity has been achieved with gas purification only, better thermal stability than 2L test stand
- The same design has been duplicated at Univ. Sheffield and Univ. Minnesota



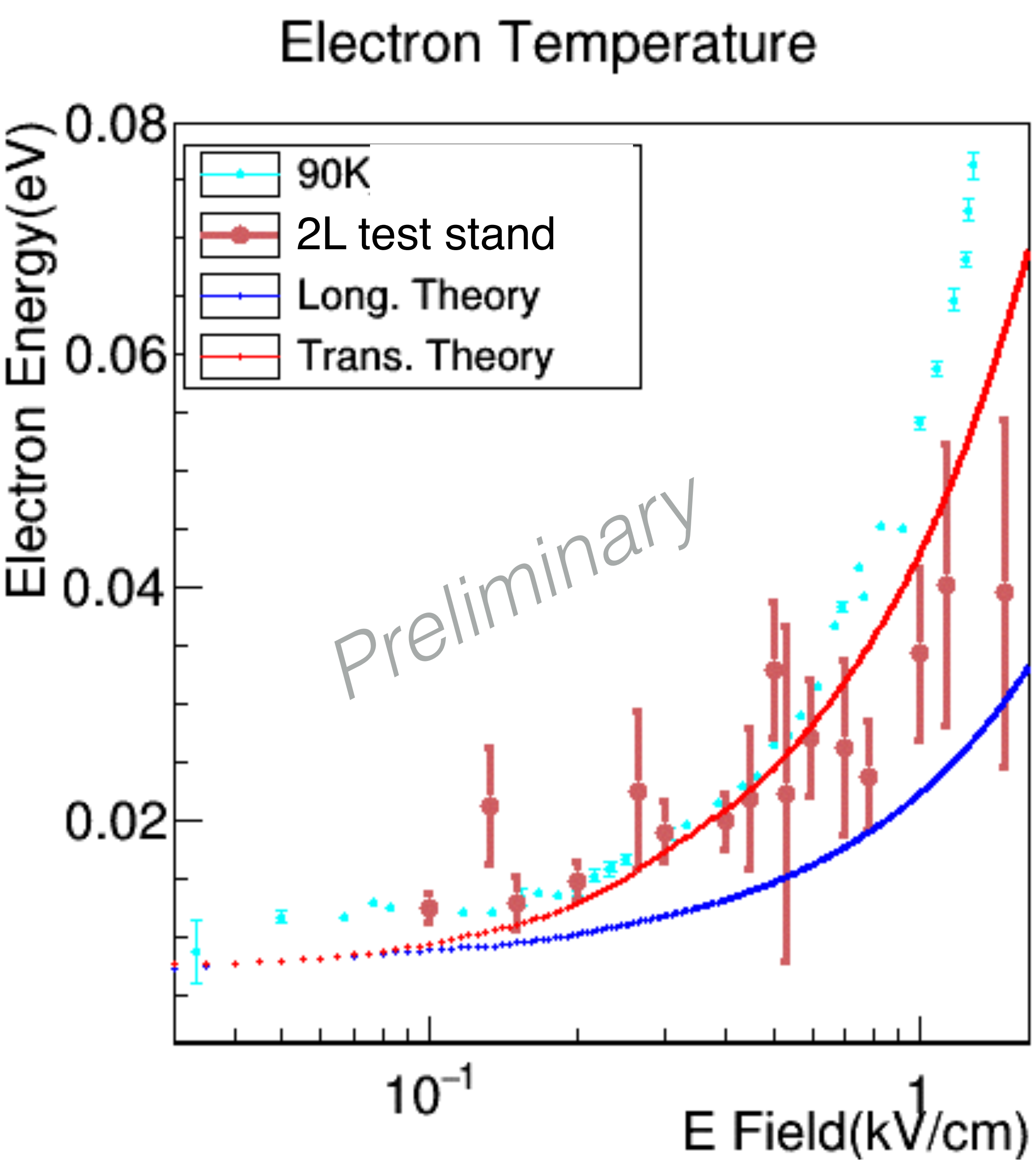
Au PhotoCahtode

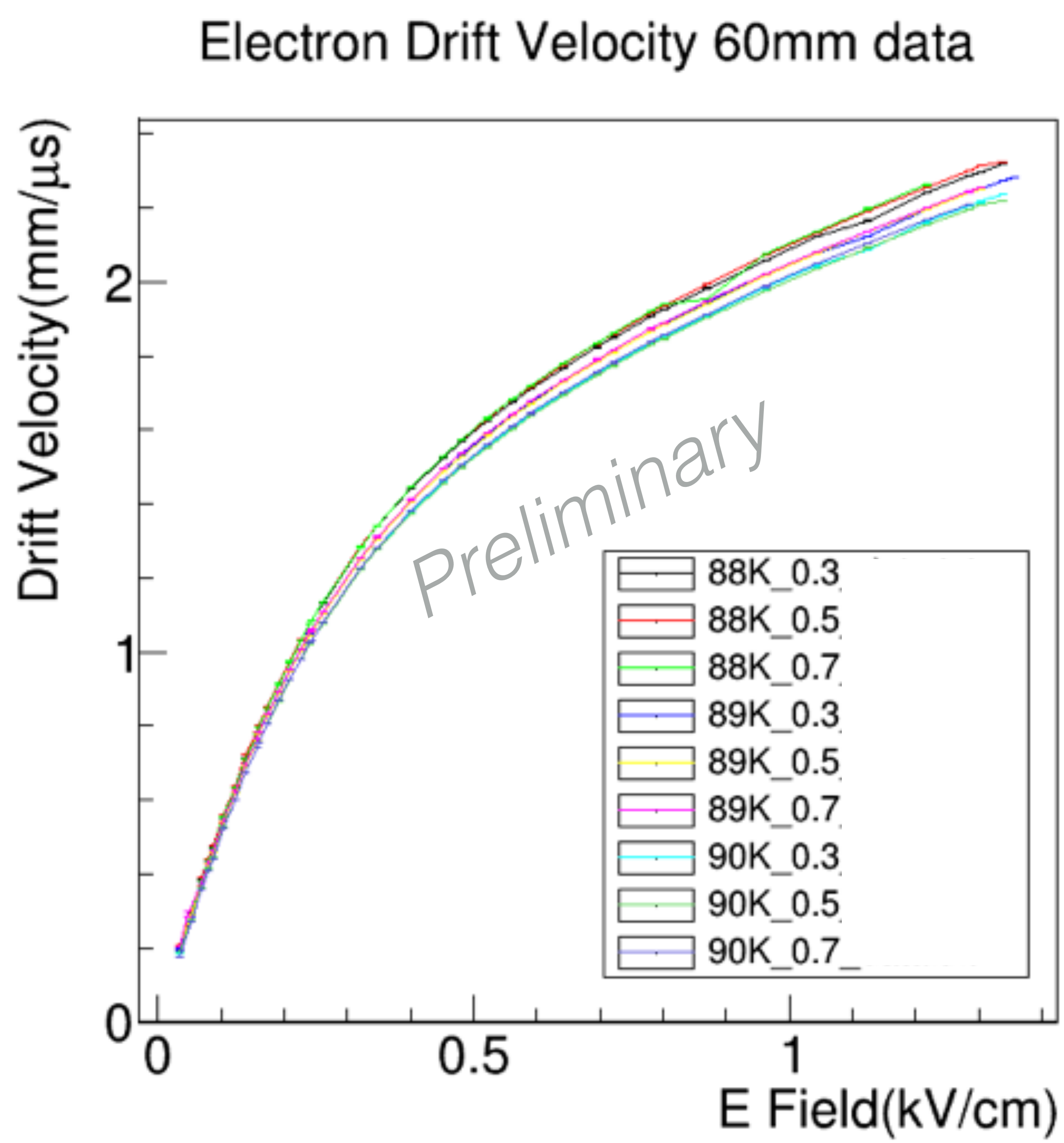


20L Test Stand: Preliminary results

- The preliminary results show good agreement with results on the 2L test stand but with better statistics and systematics

- So far we have measured drift distances of 6.5mm, 20mm, 60mm, will measure two additional drift distances (100mm and 240mm)

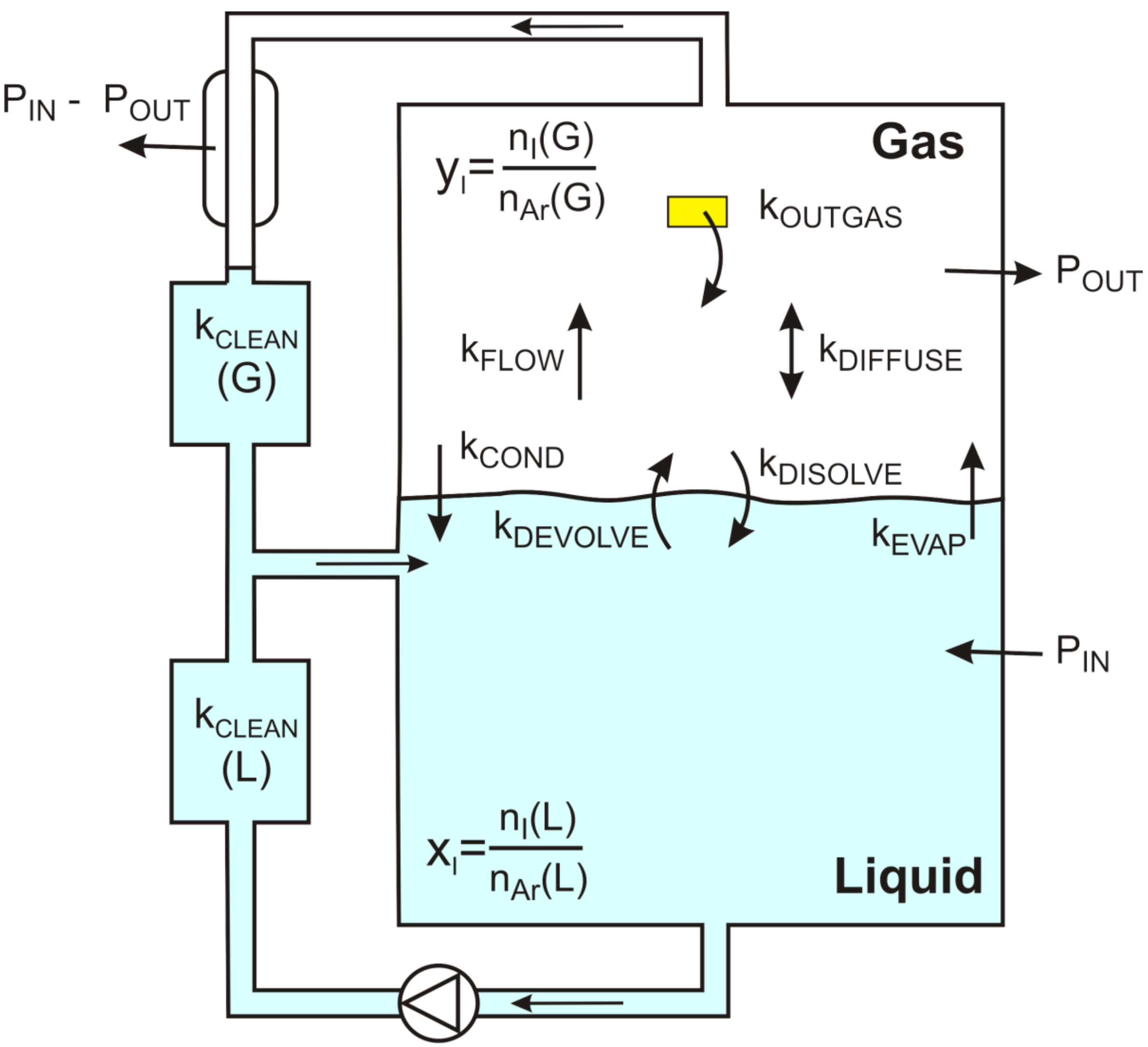




Predicting Impurity Concentrations in LAr

A Quantitative Kinetic Model of Impurity Distribution in a LArTPC

LAr cryostat/cryogenic system model

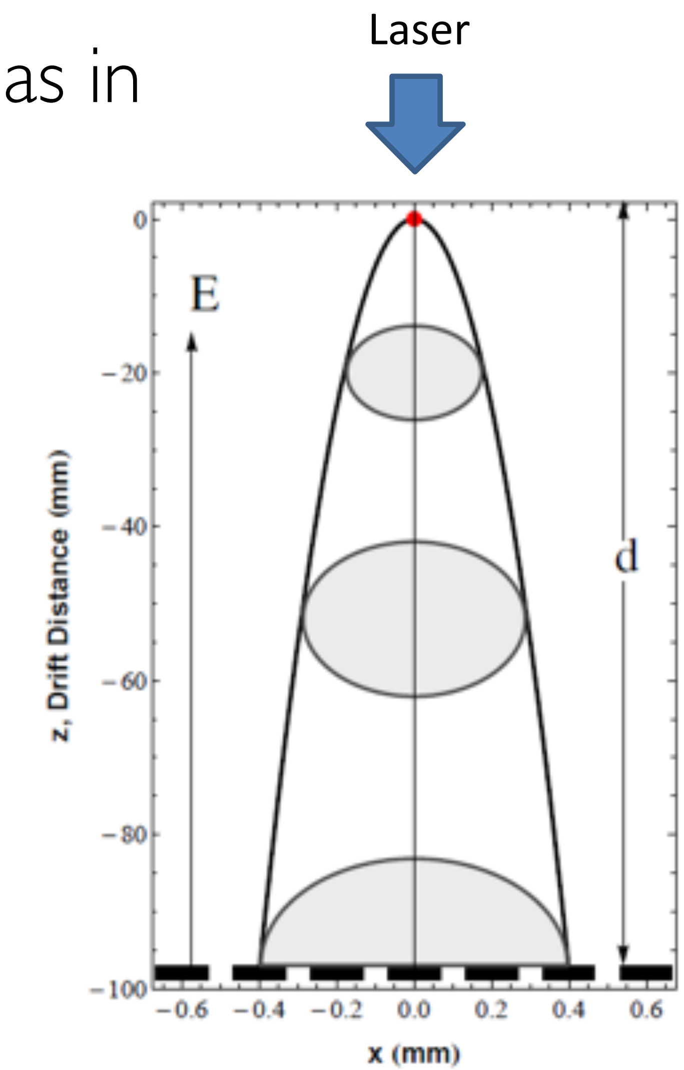


1. Impurity exchange at the gas-to-liquid interface: Henry's coefficient
2. Evaporation of the liquid
3. Condensation of the gas directly into the liquid
4. Purification of the liquid
5. Purification of the gas followed by condensation
6. Outgassing of the surfaces in contact with warm gas

Transverse Diffusion Measurement

Transverse diffusion will be measured by the similar method as in
E. Shibamura, *et al.*, Phys. Rev. A20 (1979)

$$n = \frac{n_0}{4\pi D_T t(4\pi D_L t)^{1/2}} \exp\left[-\frac{x^2+y^2}{4\pi D_T t}\right] \exp\left[-\frac{(z+v_d t)^2}{4\pi D_L t}\right]$$



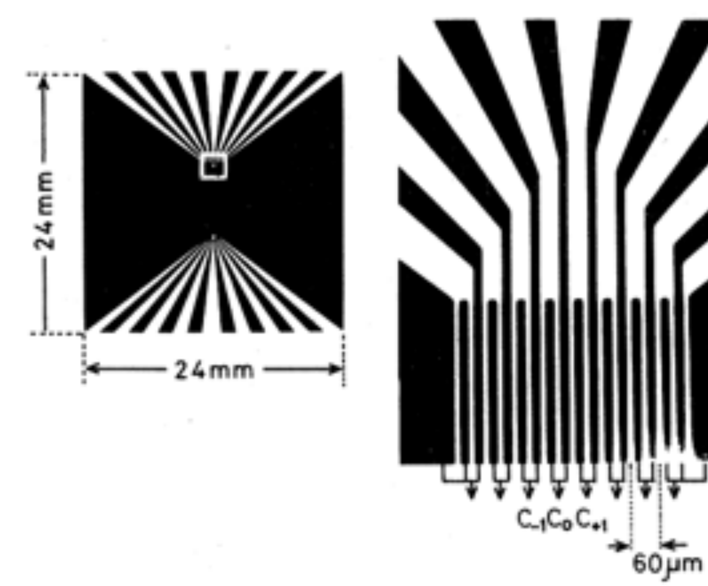
Can be written as:

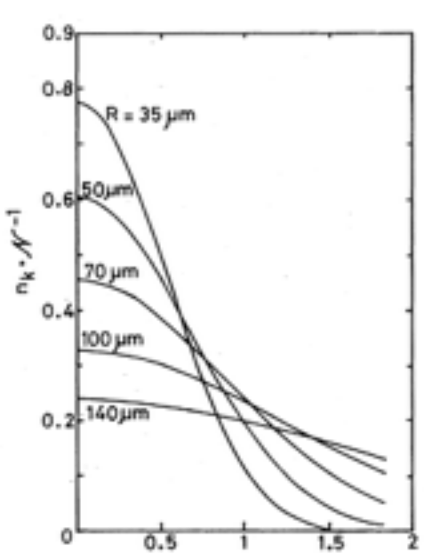
$$n(r) = \frac{n_0}{\pi^{1/2} R^3} \exp\left[-\frac{r^2}{R^2}\right]$$

$$r^2 = x^2 + y^2 + (z^2 + v_d t^2) \qquad\qquad R^2 = 4D_T t$$

The number of electrons n_k that arrive at the collector c_k can be calculated by integration over each collector.

$$R = \sqrt{4D_T t}$$





is the transverse radius of the electron swarm

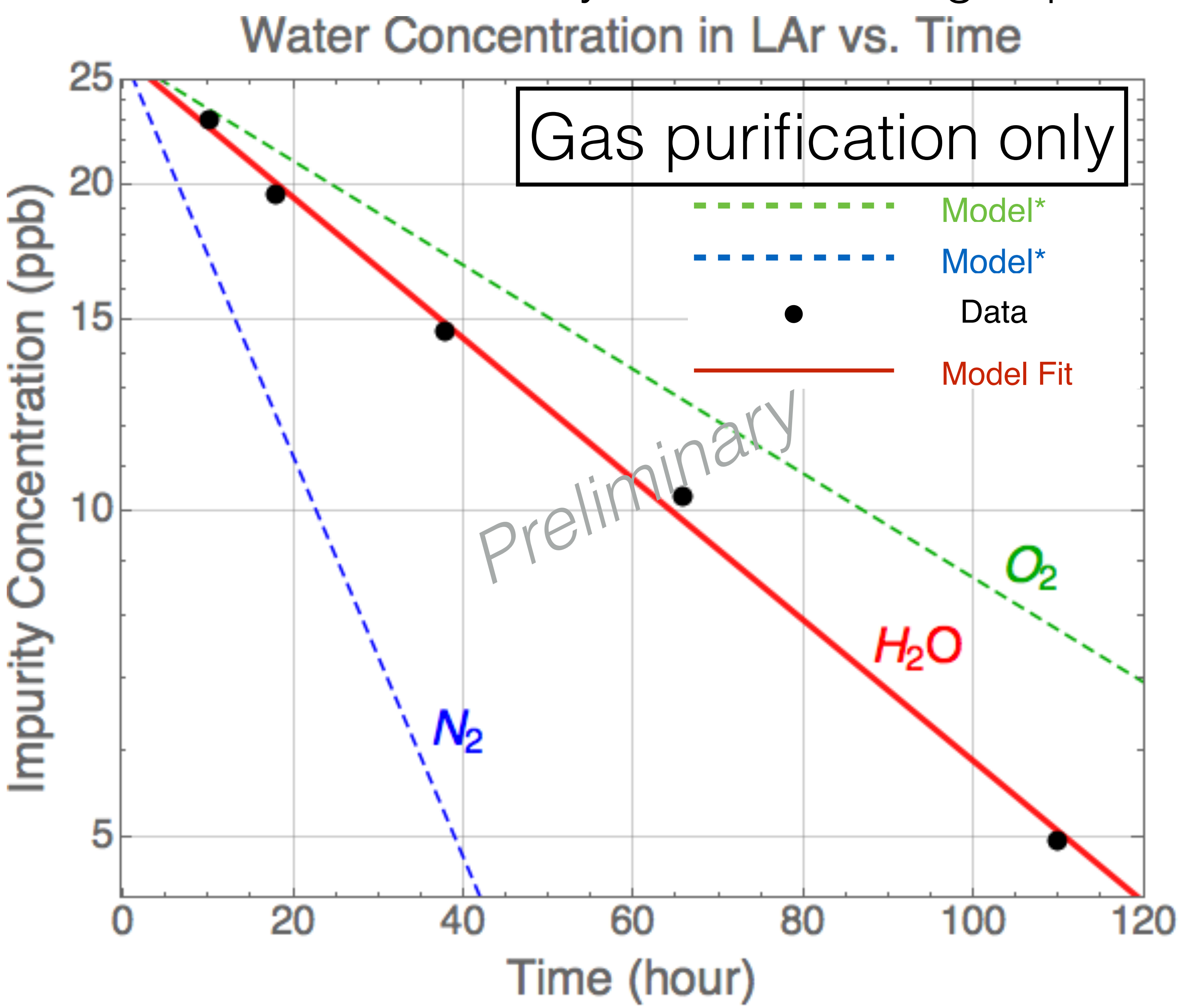
$$\frac{eD_T}{\mu} = e\frac{R^2}{4t}\frac{E}{v_d} = e\frac{R^2 V}{4d^2}$$

*Small spot size of laser is crucial for transverse diffusion measurement

Henry's Coefficient for Water

Determined from clean-up curve

- H_2O appears to have a large (but unknown) attachment rate, its Henry's constant is also unknown
- Henry's constant can be derived from clean-up curve. Such a large value —> water can be efficiently removed with gas purification



H_2O in LAr:(preliminary)

$H_{xx} = 1.2 \pm 0.2$

$k_{Outgas} \sim 10^{-9}$ mole m^{-2} s^{-1}

$k_{Disolve} < 8 \times 10^{-2}$ mole m^{-2} s^{-1}

$$H_{xx} = \frac{n_{Ar,Liquid}}{k_{Evap}\tau_{Clean}}$$

$$[H_2O]_{t\to\infty} = \frac{k_{Disolve}k_{Outgas}}{k_{Evap}{}^2 H_{xx}}$$

* *With the assumption of 100% purification efficiency*

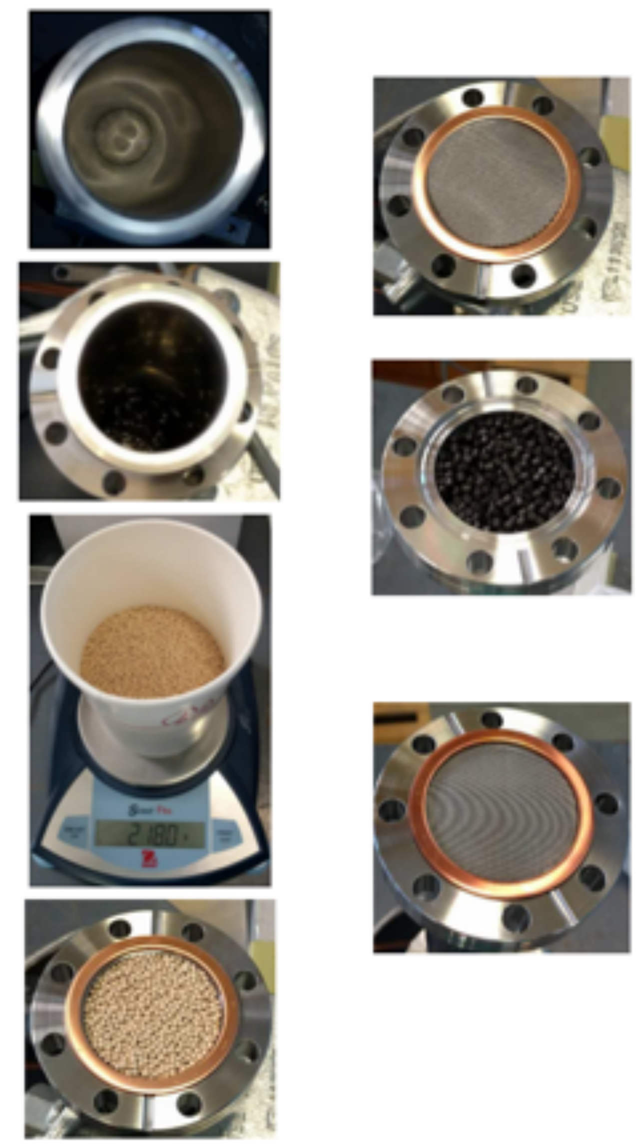
20L Improvement and purifier study

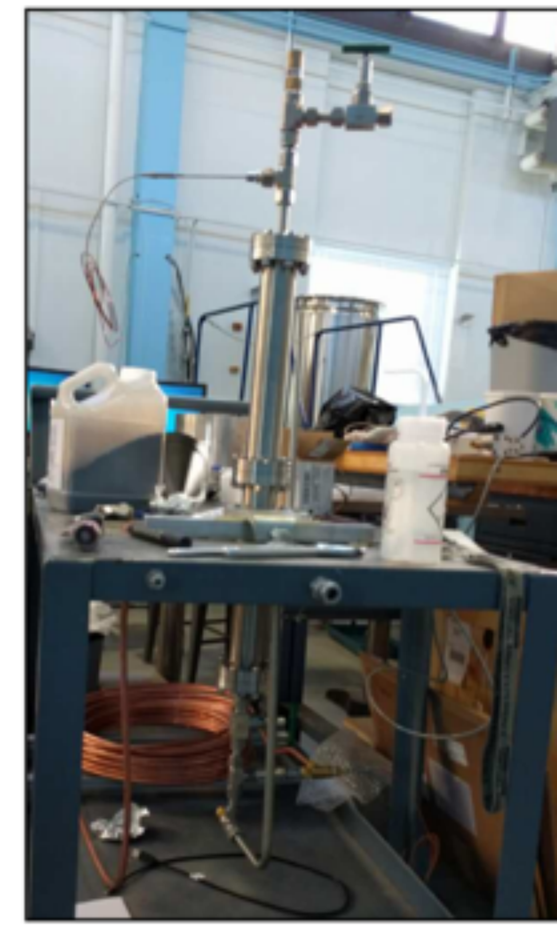
1. Due to the limit of gas purification, the initial time to establish ultra-high purity is long (~1 weeks)

2. A inline filter upon the filling is expected resolve the issue

3. A quantitative model of purifier we have will be verified

4. The purifier material property including capacity and radioactivity etc are also of insteret





LArFCS Construction

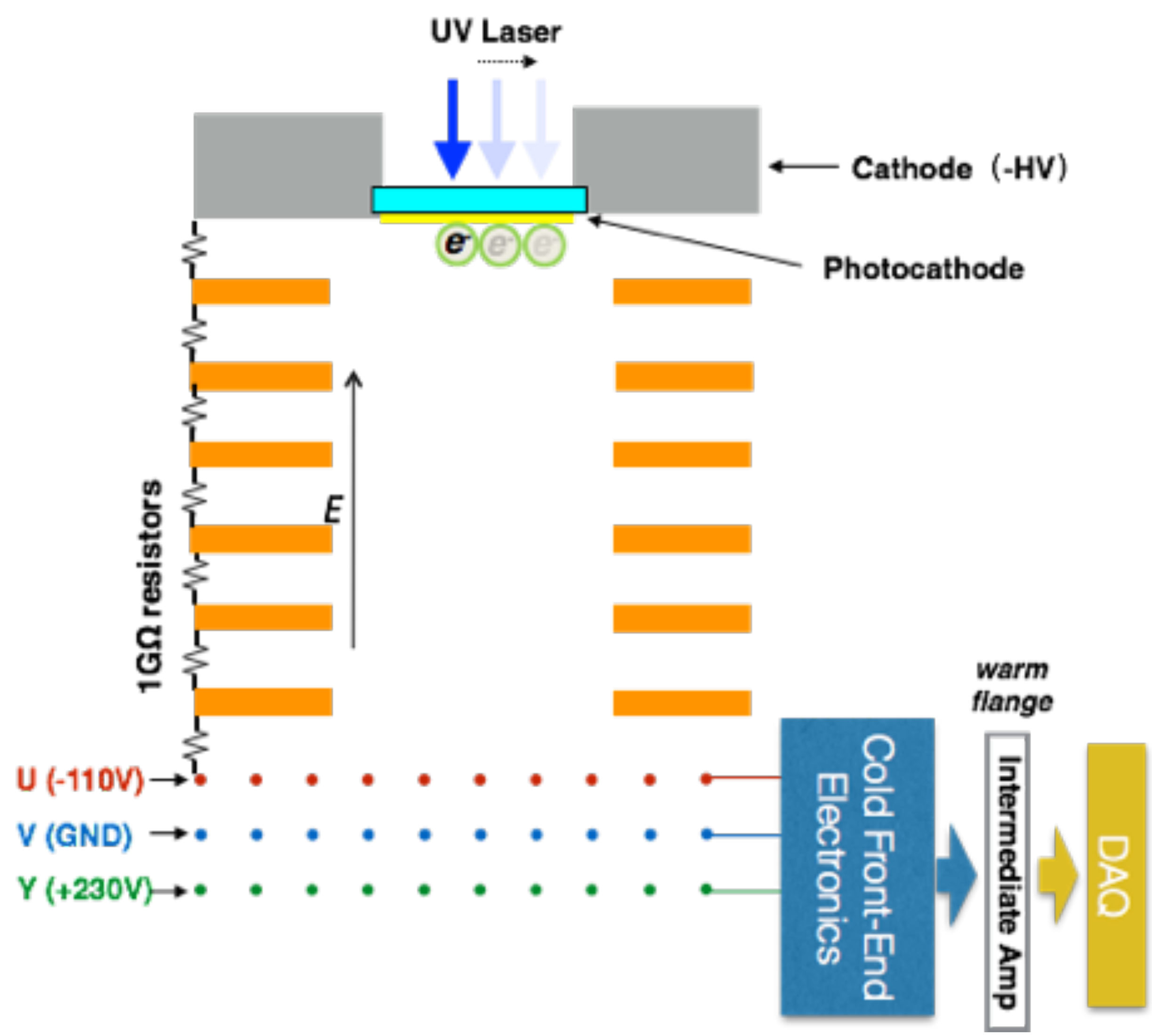
Field Response Measurement Scheme

1. The very first application of the field response measurement is for MicroBooNE

2. A TPC is required to reproduce the field conditions of MicroBooNE

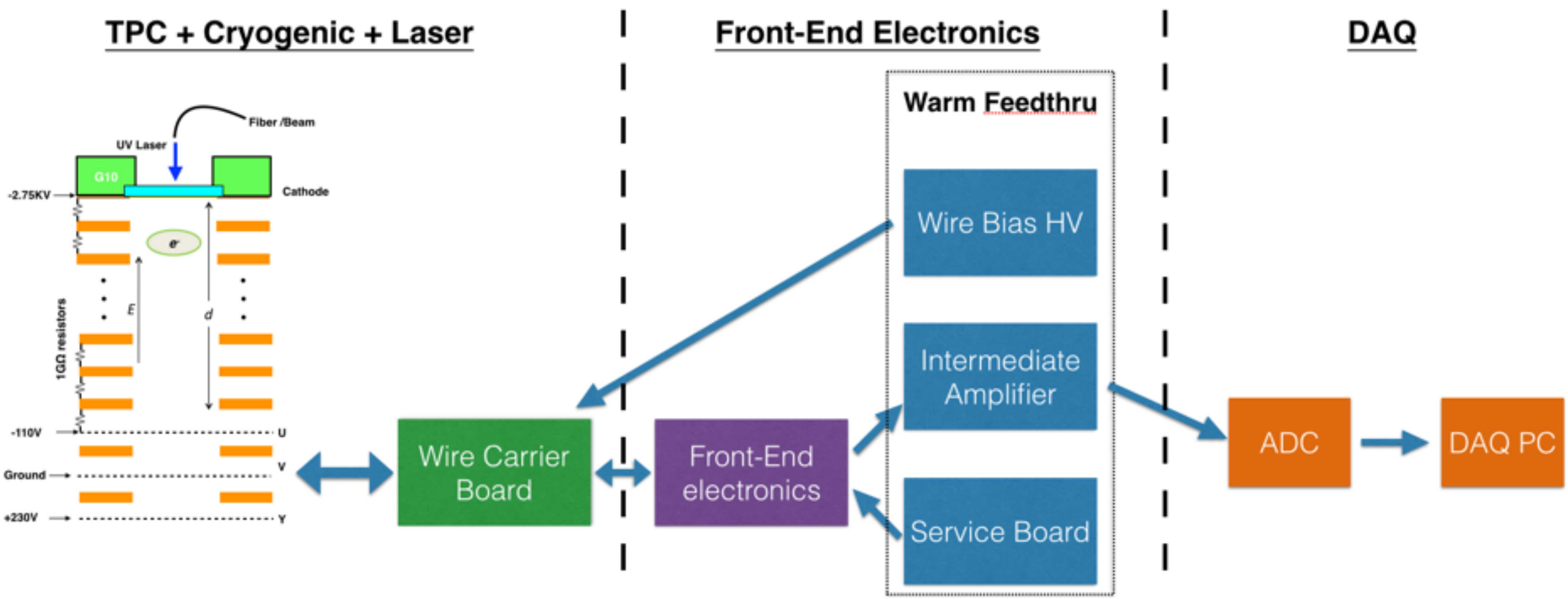
3. Point electron source at varied locations are preferred

4. The wire plane configuration would be the same as MicroBooNE



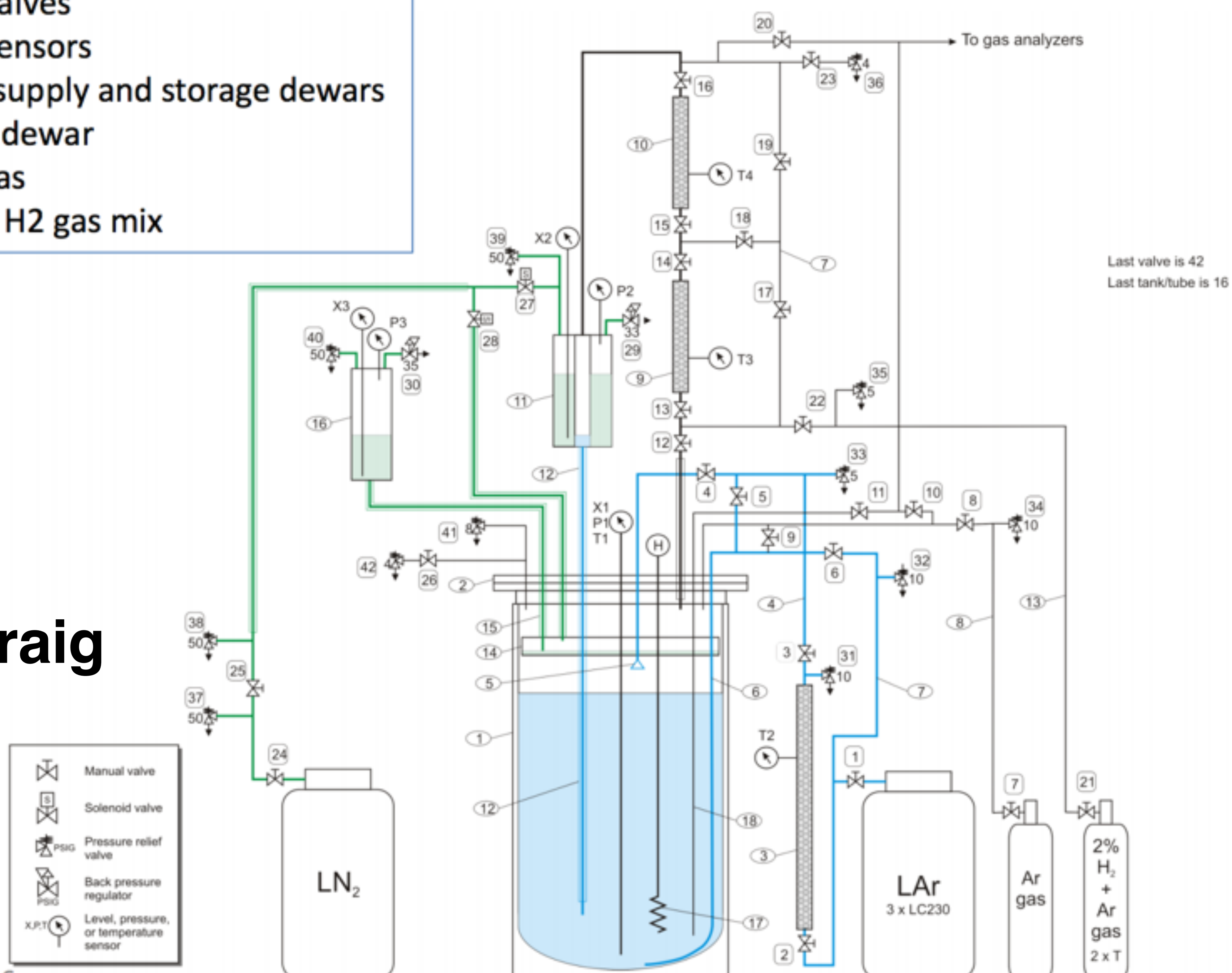
LArFCS Work Structure

1. The entire project can be divided into 3 tasks
2. Each individual task have clear border and can be proceeded in parallel
3. Good opportunity to get hand-on experience with hardware



Cryogenic System P&ID

42 valves
17 sensors
LAr supply and storage dewars
LN2 dewar
Ar gas
Ar + H2 gas mix



From Craig

7/22/2016

TPC Construction

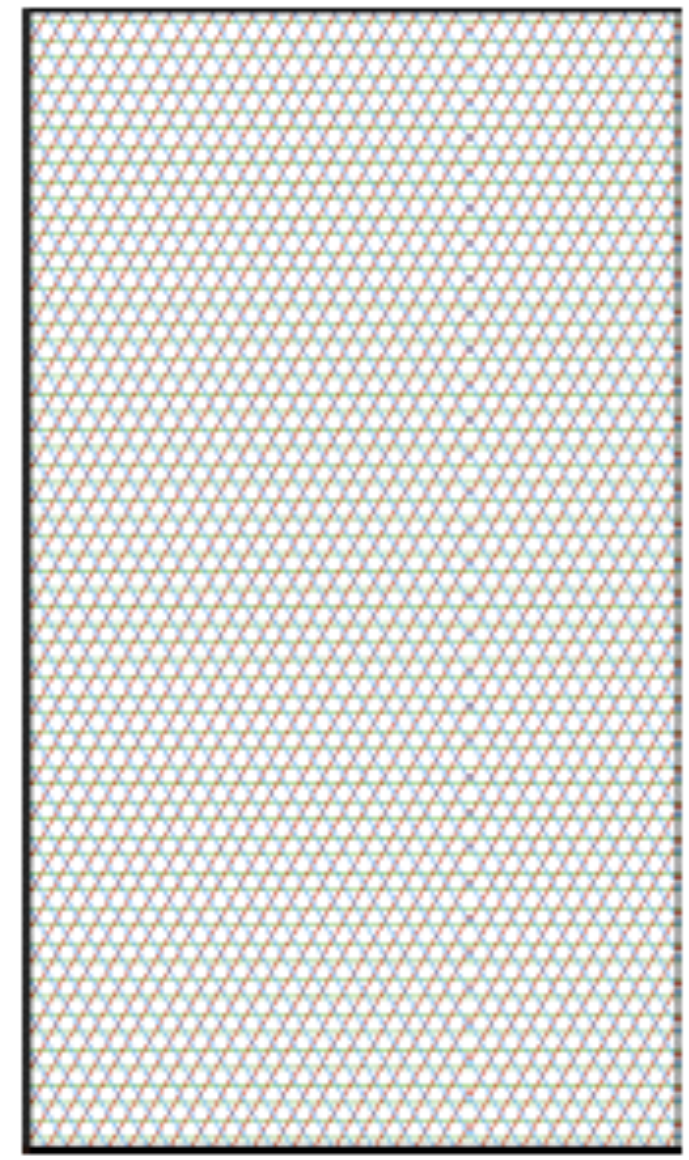
1. The key components of the TPC dimensions are:
   a. Wire pitch (3mm)
   b. Wire plane number (3 planes: U, Y, W)
   c. Wire angle (60 degree)
   d. Drift distance (~20 cm)

2. With rectangle shape TPC. The overall dimensions are
   19.9 cm x 11.1 cm x 22.0 cm

3. Wire configuration:
   U: 64 x V: 64 x Y: 64

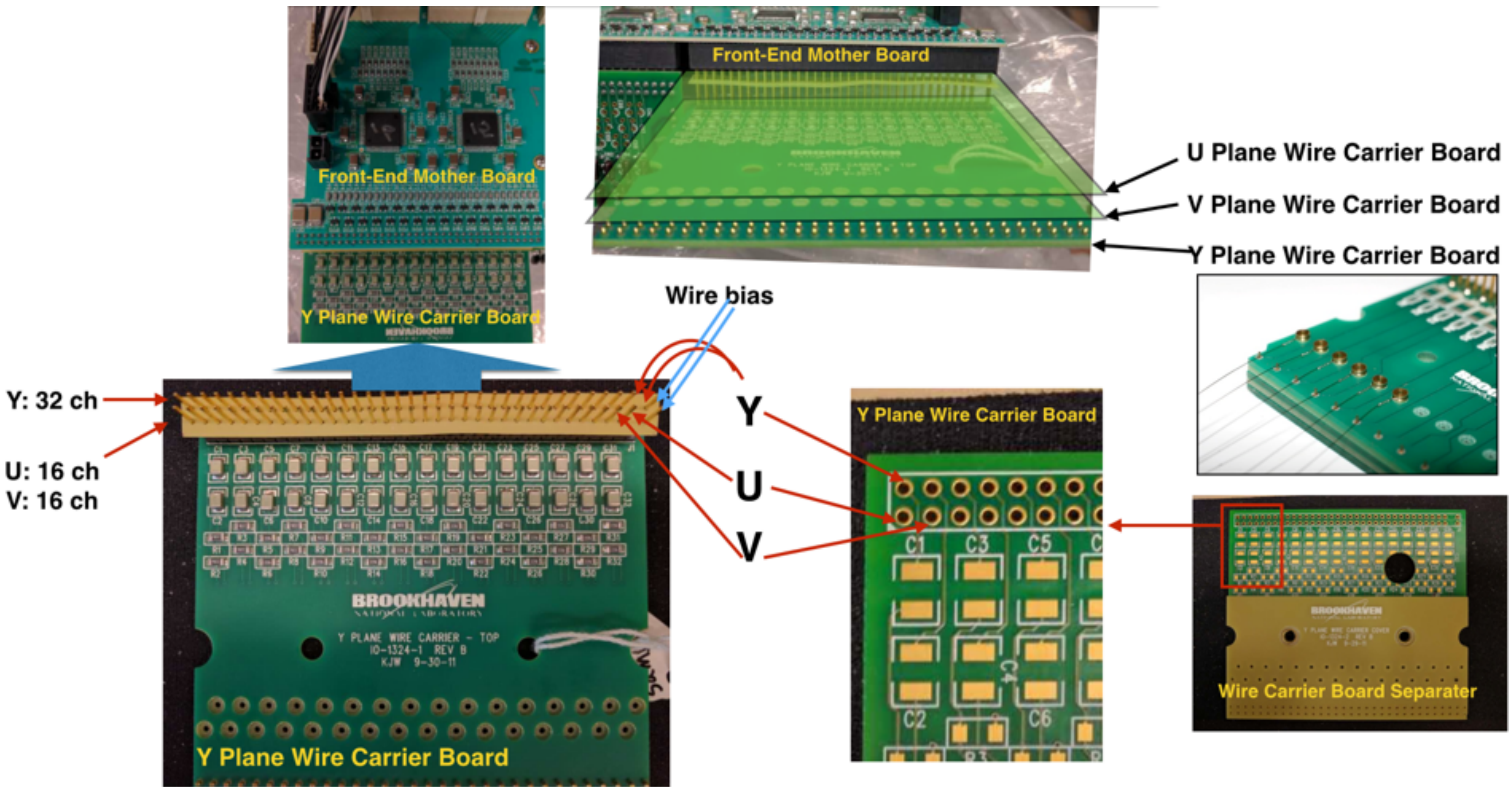
4. A single MicroBooNE Front-End mother board contains 192 channels.

5. 128 channels will be readout by commercial ADC



LArFCS TPC anode configuration

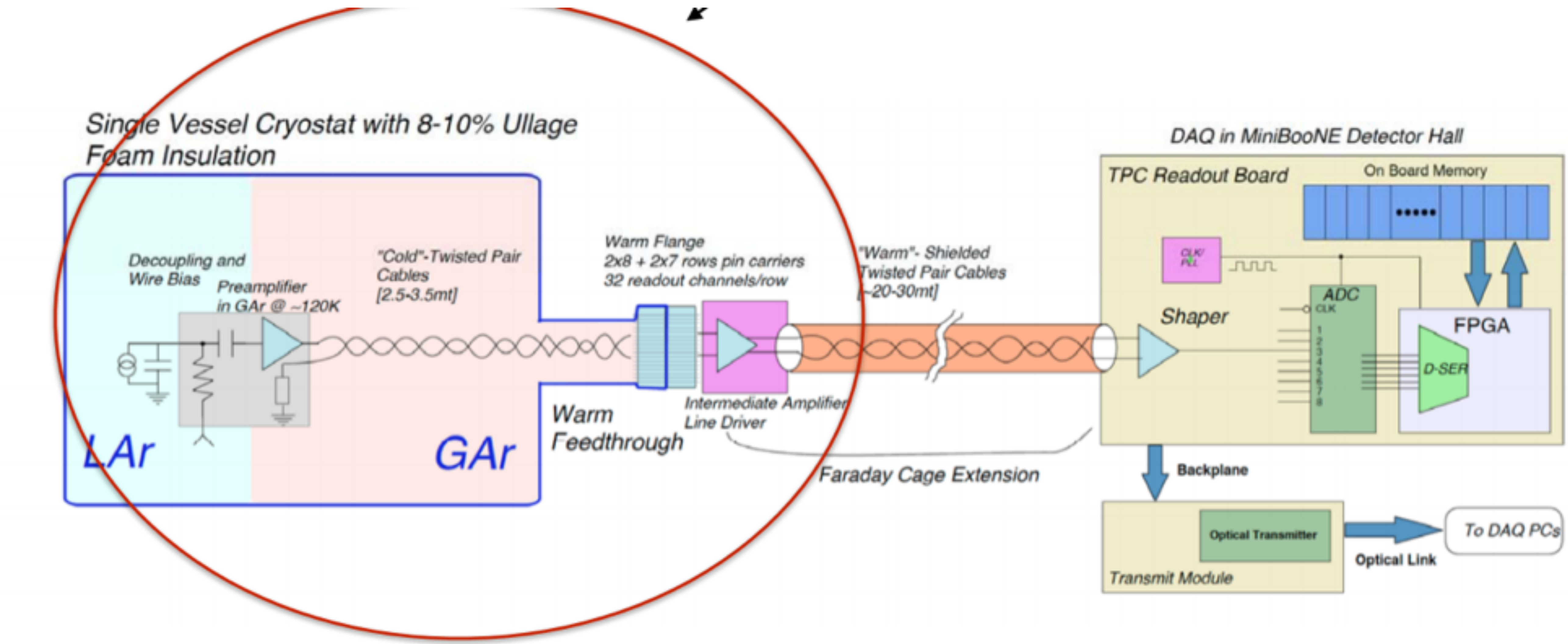
MicroBooNE wire scheme



LArFCS Front-End Electronics (Cold)

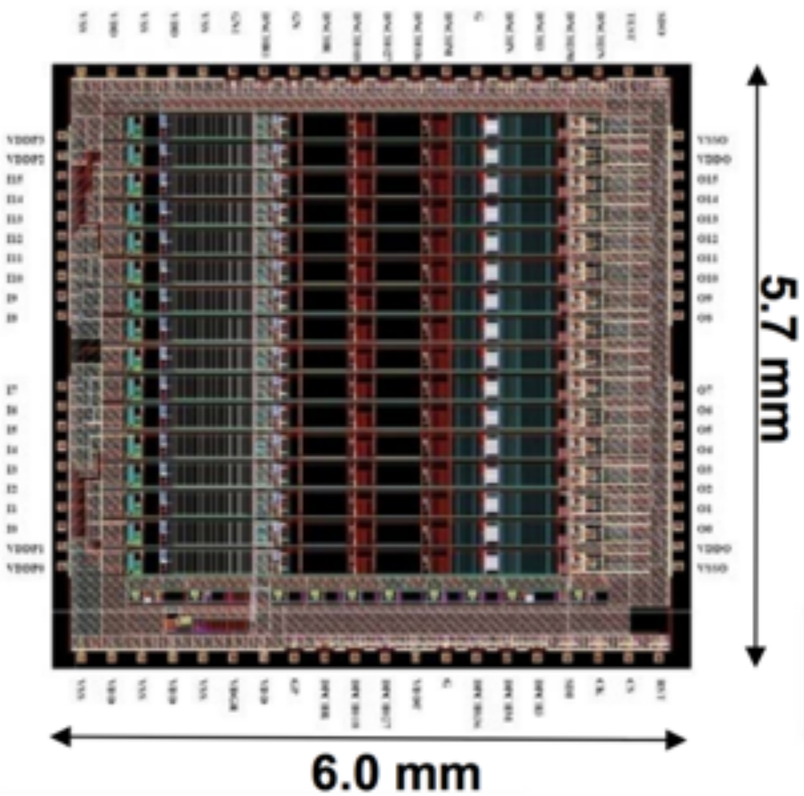
1. We are going to use MicroBooNE front-end electronics for both warm and cold

2. Existing MicroBooNE electronics can accelerate the progress

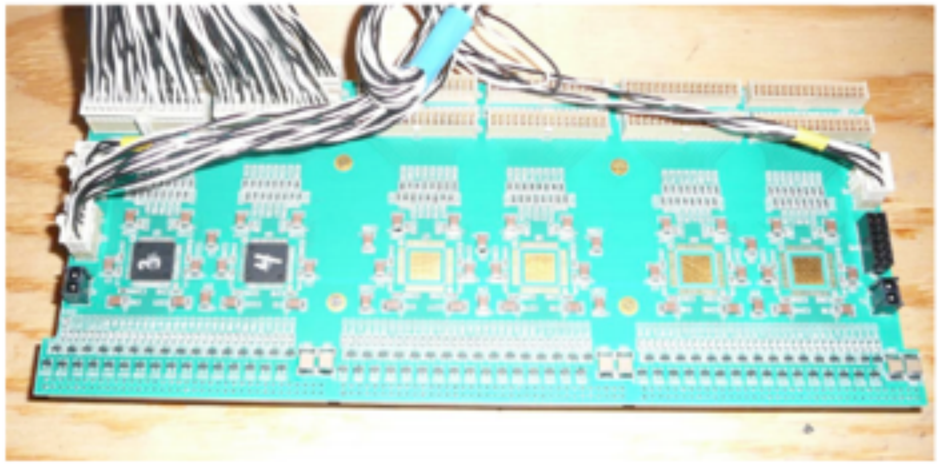


Electronics In the Cryostat (Cold)

CMOS FE ASIC



Cold MotherBoard with ASIC



Cold Cable

* Cold MotherBoard (MB):
- House FE ASICs
- Provides detector signal interconnections
- Provides ASIC control and monitoring signals, calibration network
- Bias voltage distribution for wire planes
- Two available designs from uBooNE TPC layout
    - Horizontal (48 U, 48 V, 96 Y channels)
    - Vertical (96 U or V channels)

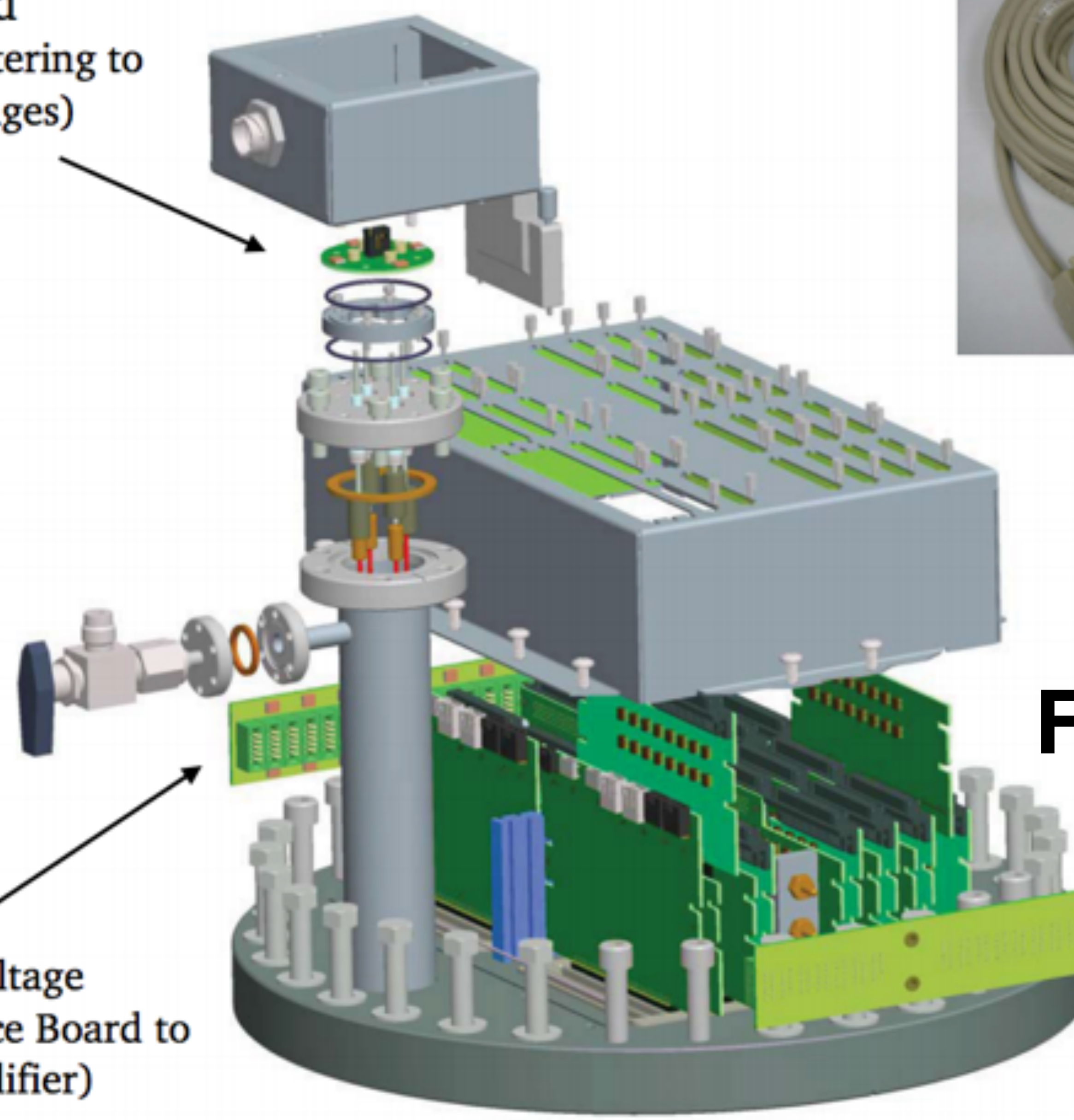
From Jyoti

FE ASIC Data Sheet: Docdb #4899

LArFCS Front-End Electronics (Warm)

Signal FT Flange

Bias Voltage Filter Board
(Provides Filtering to bias voltages)



Power Bus
(Provides Low Voltage distribution from Service Board to Intermediate amplifier)

Warm Cable

From Jyoti

Integration: Top Flange Design

1. Build an all-in-one flange is hard and not easy for modification/upgrades

2. We can distribute the functions to several flanges, each with an individual opening on the top flange for a subsystem

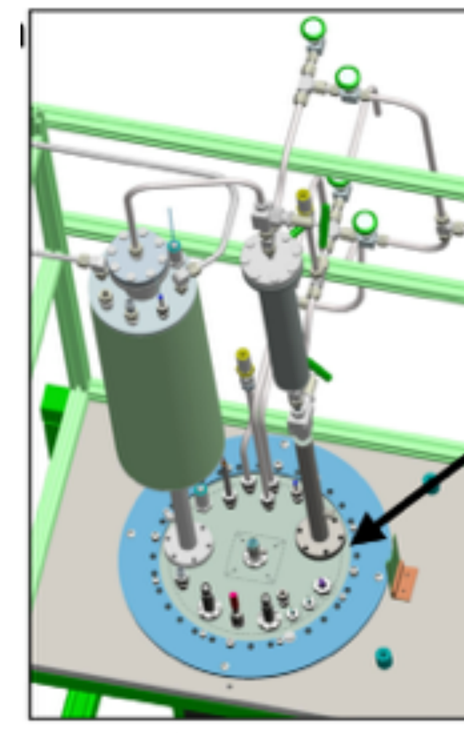
3. The existing flange design for 20-L system can satisfy our need for cryogenic

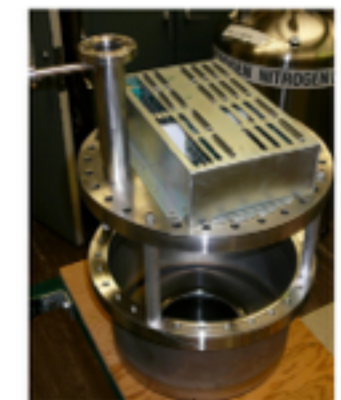
4. The slow control sensors and cryogenic feeding can all go through this feed thru

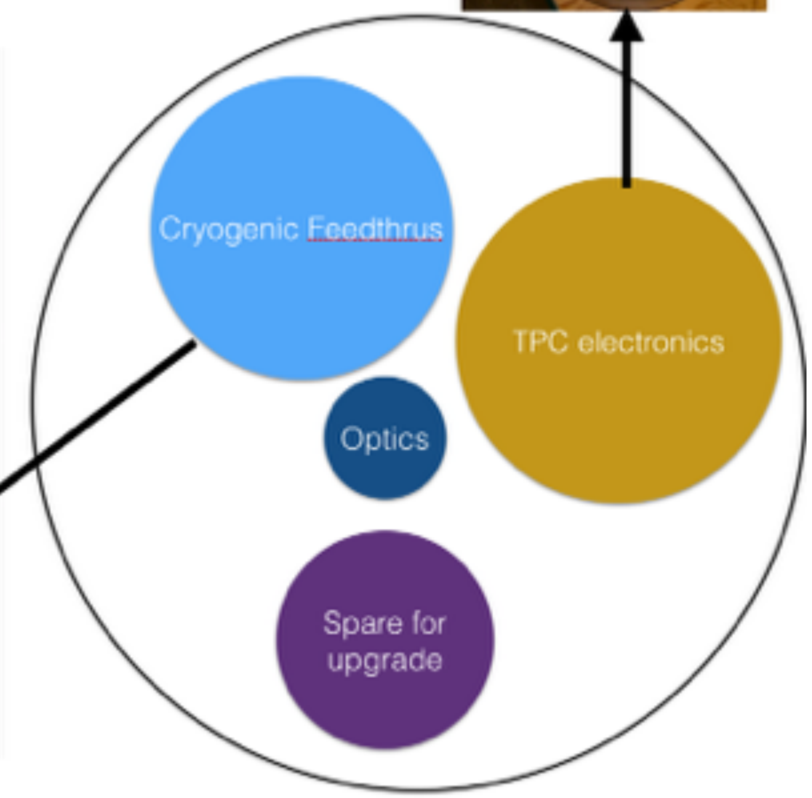
5. The TPC electronics feed uses the MicroBooNE flange

6. Need to make a new one for optics

7. Also need a careful ground scheme



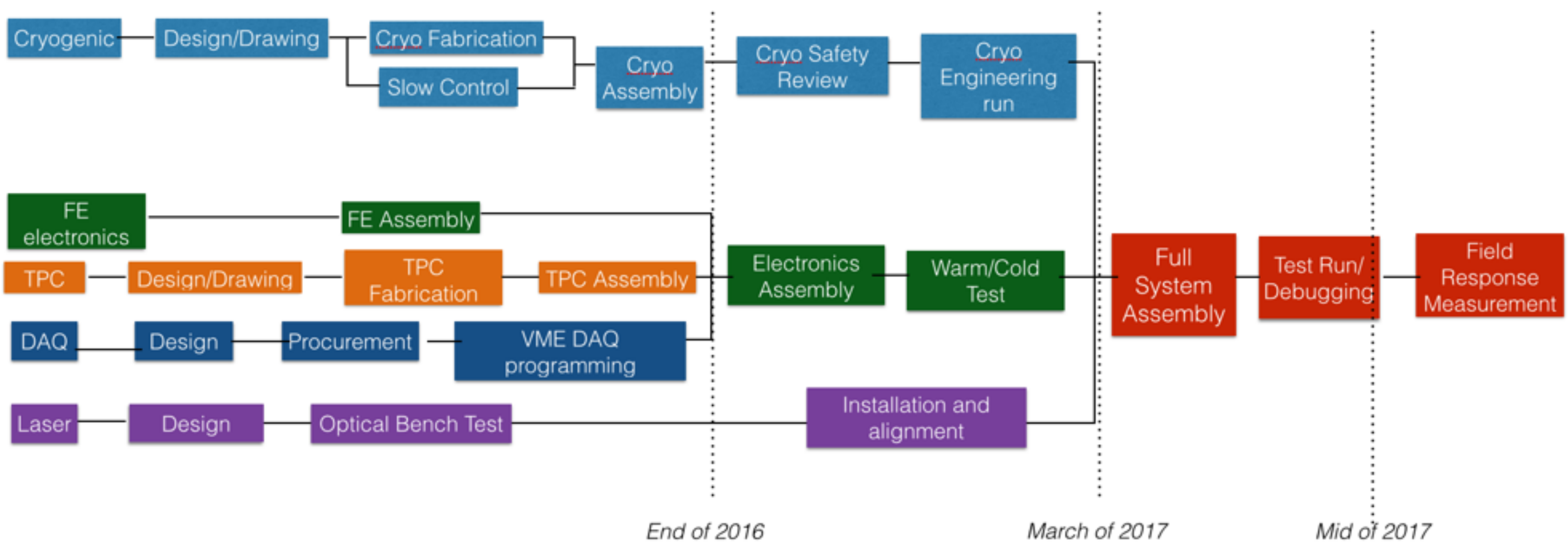




LArFCS Timeline

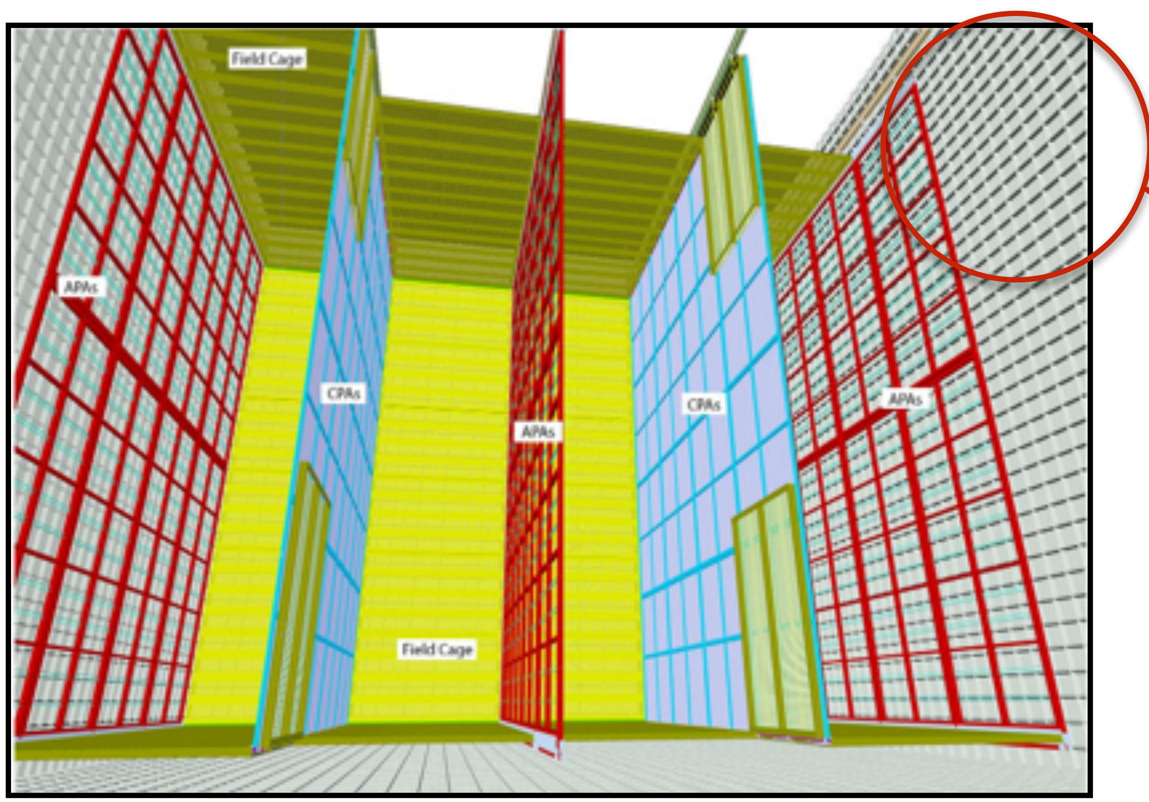
1. The LArFCS now has strong physics motivation and clear technical goals

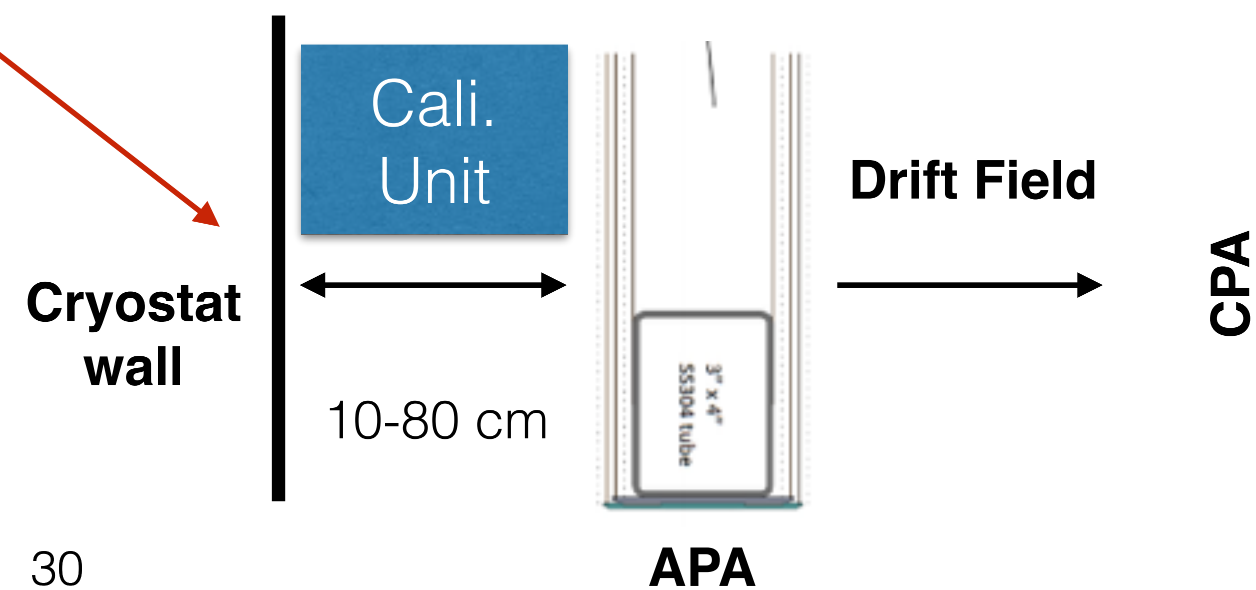
2. We plan to move in a fast pace as the requirement of knowing field response function is very time sensitive



In-situ Field Calibration Device Concept

- The ultimate goal of LArFCS is to implement a in-situ field calibration device in DUNE
- The APA plane facing towards the cryostat wall is not used at this moment is ideal location to install the unit
- Uniform electric field can be generated by a short field cage.
- A bias HV of only <10 kV is enough to maintain the drift field of 0.5 kV/cm





Summary

1. It is important to understand the properties of LAr for current/future large LArTPCs

2. BNL has a R&D program dedicated to LAr properties study

3. Our current longitudinal diffusion results with the 2L test stand represent the world's best measurement in the region between 100 to 2000 V/cm

4. The Impurities model will be verified with the 20L test stand and LArFCS

5. LArFCS will demonstrate the capability of gas purification for large LArTPC —> optimization of detector design

6. LArFCS would address the important field response function issue

7. The ultimate goal is to implement a in-situ calibration device in DUNE

8. Good opportunity to get hardware experience. Help welcomed:)